Use of biomass fuels in the brick-making industries of Sudan: Implications for deforestation and greenhouse gas emission

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Thesis submitted for an M. Sc. Degree in Forest Ecology
/Tropical Silviculture

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Helsinki, April 2006

HELSINGIN YLIOPISTO – HELSINGFORS UNIVERSITET – UNIVERSITY OF HELSINKI

Tiedekunta - Fakultet - Faculty	Laitos - Institution - Department
Faculty of Agriculture and Forestry	Forest Ecology/Viikki Tropical Resources Institute (VITRI)

Tekijä - Författare - Author

Alam, Syed Ashraful

Työn nimi - Arbetets title – Title

Use of biomass fuels in the brick-making industries of Sudan: Implications for deforestation and greenhouse gas emission

Oppiaine - Läroämne - Subject

Tropical Silviculture

Työn laji - Arbetets art - Level	Aika - Datum - Month and year	Sivumäärä - Sidoantal - Number of pages
M. Sc. thesis	April 2006	87

Tiivistelmä - Referat – Abstract

The study focuses on the potential roles of the brick making industries in Sudan in deforestation and greenhouse gas emission due to the consumption of biofuels. The results were based on the observation of 25 brick making industries from three administrative regions in Sudan namely, Khartoum, Kassala and Gezira. The methodological approach followed the procedures outlined by the Intergovernmental Panel on Climate Change (IPCC). For predicting a serious deforestation scenario, it was also assumed that all of wood use for this particular purpose is from unsustainable sources.

The study revealed that the total annual quantity of fuelwood consumed by the surveyed brick making industries (25) was 2,381 t dm. Accordingly, the observed total potential deforested wood was 10,624 m^3, in which the total deforested round wood was 3,664 m^3 and deforested branches was 6,961 m^3. The study observed that a total of 2,990 t biomass fuels (fuelwood and dung cake) consumed annually by the surveyed brick making industries for brick burning. Consequently, estimated total annual emissions of greenhouse gases were 4,832 t CO_2, 21 t CH_4, 184 t CO, 0.15 t N_20, 5 t NO_X and 3.5 t NO while the total carbon released in the atmosphere was 1,318 t. Altogether, the total annual greenhouse gases emissions from biomass fuels burning was 5,046 t; of which 4,104 t from fuelwood and 943 t from dung cake burning.

According to the results, due to the consumption of fuelwood in the brick making industries (3,450 units) of Sudan, the amount of wood lost from the total growing stock of wood in forests and trees in Sudan annually would be 1,466,000 m^3 encompassing 505,000 m^3 round wood and 961,000 m^3 branches annually. By considering all categories of biofuels (fuelwood and dung cake), it was estimated that, the total emissions from all the brick making industries of Sudan would be 663,000 t CO_2, 2,900 t CH_4, 25,300 t CO, 20 t N_2O, 720 t NO_X and 470 t NO per annum, while the total carbon released in the atmosphere would be 181,000 t annually.

Avainsanat – Nyckelord - Keywords

Biofuels, Brick-making industry, Deforestation, Dung cake, Fired clay bricks, Fuelwood, Greenhouse gas emission.

Säilytyspaikka - Förvaringsställe - Where deposited

Viikki Science Library

Muita tietoja - Övriga uppgifter - Additional information

PREFACE

This study was carried out during the summer of 2005 in four administrative States of the Sudan within the framework of the CIMO (Centre for International Mobility) North-South Higher Education Programme and in connection with ongoing research project (TALDA-Trees, agroforestry and land use in dryland Africa), supported by the Academy of Finland and implemented jointly by the Viikki Tropical Resources Institute (VITRI) of the University of Helsinki, the University of Khartoum and the Forestry Research Centre, Sudan, respectively. It was also supported by the Master's Thesis Travel Grant of the University of Helsinki.

I would like to express my heartfelt gratitude and sincerest appreciation to my supervisor Dr. Olavi Luukkanen, Professor and Director of VITRI, University of Helsinki. His meticulous supervision, continuous guidance, intimate co-operation, encouragement and comments on the draft were significantly crucial for successful completion of my Thesis. I am also deeply indebted to Dr. Omer Said Musa, Associate Professor of the Faculty of Forestry, University of Khartoum, for co-supervising the fieldwork in Sudan. Without his guidance and advice many of the interviewees could not have been done.

I gratefully acknowledge the generous logistical and/or administrative support provided by Dr. Vesa Kaarakka, University Lecturer of the Department of Forest Ecology/VITRI, University of Helsinki; Dr. Abdelazim Yassin Abdelgader, Dean, Faculty of Forestry, University of Khartoum and Dr. Abdalla Gaafar Mohamed, Chief, Technical Sector, Forests National Corporation (FNC), Sudan. I am also grateful to Dr. Edinam K. Glover, Senior Researcher of VITRI, who in the first place encouraged me to go to Sudan and helped me for writing research proposal, which I will never regret.

Grateful acknowledgement is made for the support of Dr. Mohamed Elfadl, Dr. Essam Warrag, Dr. Elnour Adallah Elsiddig and Elamin Raddad with whom I have had many fruitful discussions to accomplish the present study.

During field work in the Sudan, I got unlimited assistance from FNC staffs namely, Anwar Abdel Hamid, Isam Abdel Kareem, Burae Balla, Mohamed Gasmalla Ahmed and Fathi Ismail Omer. Thank you very much, for your kind assistance. Very special and sincere thanks go to Rahma A. Rahman Ahmed, Forestry Manager, Kenana Sugar

Company; Dr. Mohammed Hussain Hamid, Director of Brick Plant Unit, University of Khartoum and Dr. Balgis Osman Elasha, Principal Investigator of Higher Council for Environment and Natural Resources (HCENR) for their valuable information to write-up my Thesis.

I am grateful in all ways to the Field Assistants specifically Abdel Naser Ibrahim and Anwar Sid Ahmed for their help as interpreter and data collector. Special thanks also go to all the brick making entrepreneurs who provided me the interviewees and allowed me to snap their brick making activities.

I would also want to thank all the people in VITRI, explicitly Dr. Eshetu Yirdaw, Dr. Mark Appiah, Minna Hares, Anu Eskonheimo, Jörn Laxén, Sakina Elshibe, Ping Zhou, Kurt Walter and Ermo Palm.

Finally, I would like to express my deepest cordial thanks to my family especially to my mother and father for their unlimited spiritual moral support. And of course, last, but not least, to one of the most important persons of my stay in Sudan, I would like to say thanks to Fobissie.

Helsinki, April 2006

Syed Ashraful Alam

LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

AAS	Australian Academy of Science
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
BENS	Biomass Energy Network of Sudan
BMI	Brick making Industry
BRRI	Building and Road Research Institute, Sudan
CDIAC	Carbon Dioxide Information Analysis Center
CEERD-AIT	Centre for Energy-Environment Research and Development at Asian Institute
CRATerre	International Centre for Earth Construction, France
dm	Dry matter
EBRD	European Bank for Reconstruction and Development
ECE	United Nations Economic Commission for Europe
EIA	Energy Information Administration
EPA	US Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FEF	Forest Energy Forum
FNC	Forests National Corporation
Gg	Giga grams [1 Gg = 10^9 grams = 1,000 t (MT, metric tons)]
GHG	Greenhouse Gas
GWP	Global Warming Potential
ha	Hectare
HCENR	Higher Council for Environment and Natural Resources
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ITDG	Intermediate Technology Development Group
LCFRD	Library of Congress - Federal Research Division
m^3	Cubic Meter
MEM	Ministry of Energy & Mining
MEPD	Ministry of Environment & Physical Development
MTOE	Metric Tonne Oil Equivalent
NET	National Environmental Trust
NOAA	US National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
RWEDP	Regional Wood Energy Development Programme in Asia
SD	Standard Deviation
SEHD	Society for Environment and Human Development
t	Ton
TOE	Ton Oil Equivalent
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WB	The World Bank
WEC	Wood Energy Council
WMO	World Meteorological Organization

CONTENTS

1 INTRODUCTION

From earliest times, biomass[1] has provided food, fuel, feed, feedstock, fibre, and fertilizer (the so-called "6Fs") to humankind. At present, biomass is the world's fourth largest energy source, providing about 13% of the world's energy consumption. In developing countries it is the most important source of energy, reaching 33% of the total energy use. Its share in industrialized countries averages only 3% of their total energy consumption. Nearly 2 billion people in developing countries depend on traditional fuels (wood, dung, and crop residues) (Hall *et al*., 1999; WMO, 2001). IPCC, Shell, IEA, and the UNCED predicted that after the year 2020, biomass and some other renewable energies will play a significant and increasing role in the world's future energy mix (Hall, 1998).

There is an important contribution of biomass fuels in the total primary energy supply of developing countries. Most of the biomass fuels used come from forests, mainly wood and charcoal. In 1995, a total of 3,350 million m^3 of wood harvested world wide, of which 63% used for energy production (FAO/FEF, 2000). Of the total world wood-fuel consumption, Asian countries have the highest share, with 43.6%; followed by Africa, with 21.1%; Canada and the United States, 11.8%; Latin America, 11.7%; and Europe, with 8.5% (Fig. 1). In some countries, the share of agriculture residues and animal dung is also significant. FAO has estimated that about 800 million people in the world rely on crop residues and animal dung for energy, especially in certain parts of the developing world where fuelwood is scarce (Hall *et al.*, 1992; Thomas *et al.*, 1997). Crop residues used for energy vary from place to place. The most important ones are sugarcane bagasse[2], rice husks, and corncobs. Animal dung largely contributes as an energy source for cooking in rural households of some Asian countries like Bangladesh, India, Pakistan, Bhutan, Nepal, and Vietnam, and also in Peru. After being collected, dung is usually compacted and dried in the sun before being used as a mixture with wood (Bala and Hossain, 1992; Lefevre *et al.*, 1997)

[1] Biomass: All kinds of material coming directly or indirectly from contemporary photosynthesis reactions, such as all vegetal matter and derivatives; woodfuel, charcoal, paper, dung, and a large portion of urban refuse (FAO as cited in WMO, 2001).

[2] Bagasse is the fibrous residue of cane stalks resulting from crushing and extraction of the juice (BENS, 1996).

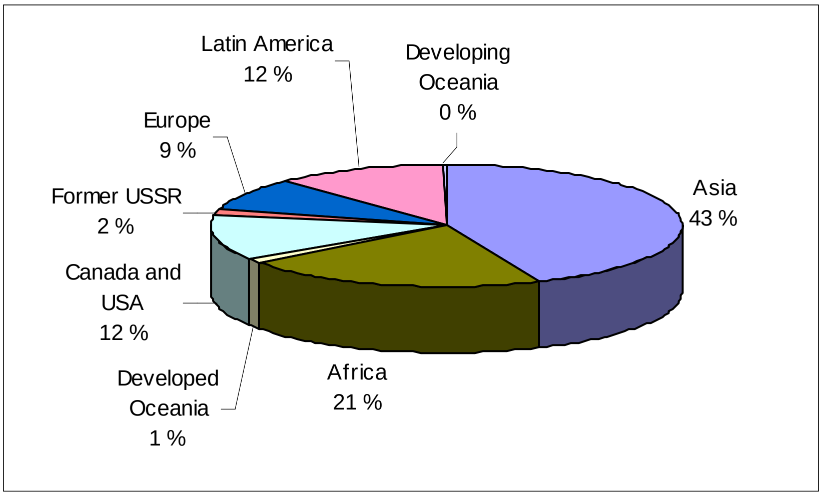

Figure 1. Distribution of wood energy consumption by regions, 1995. (Adapted from WEC/FAO, 1999)

Sudan, the largest country in Africa, encompasses an area of about 2.51 million km^2. The Sudan lies within the tropical zone between latitudes 3^0 and 20^0 North and longitudes 22^0 and 38^0 East. The total annual production of fired clay bricks in the Sudan is estimated to be about 2.8 billion. This is mainly produced by traditional methods where biomass fuels[3] (fuelwood and dung cake) are used for brick burning. Modern brick production where fuel oil is used covers less than 2% of the total annual brick production. Therefore, biomass fuels, especially fuelwood, are the main fuels used in clay brick firing. The total annual consumption of wood in the brick making industries of the Northern States of Sudan is found to be about 550,000 stacked m^3 (Hamid, 1994; BENS, 1996).

Consumption of biomass fuels (fuelwood, crop residues, dried animal waste etc.) is often considered to be neutral with respect to emissions of carbonaceous greenhouse gases, which means all the CO_2 emitted in the burning process is taken up in the following growing season by replacement crops and trees. However, only when the biomass fuels are harvested on a sustainable basis (a new tree planted for each tree cut down for fuelwood) and only when all the carbon in the fuel is converted to CO_2 can the process be considered truly carbon-neutral. Even when the biomass fuels are assumed to be harvested on a completely sustainable basis (all CO_2 emissions reabsorbed in the following growing season), products of incomplete combustion (CO-carbon monoxide,

[3] Biomass fuels include all the organic fuels from biological origin used for energy purposes. It includes all terrestrial and aquatic vegetation, its residues such as fuelwood, twigs, dead leaves, and shell, cultivated crops and their residues like cereal straw, seed-husks, bagasse; livestock products, and their residues (e.g. dung) (CEERD-AIT definitions as cited in WMO, 2001)

CH_4-methane and NMHC-non-methane hydrocarbons) emissions from biomass fuels combustion account for 4.5% of the total carbon emissions and 23% of CO_2 equivalents on a short-term (20-year) GWP basis. In addition, combustion efficiency is inversely related to the formation of products of incomplete combustion. In other words, lower combustion efficiencies lead to higher products of incomplete combustion emissions (Streets and Waldhoff, 1999).

In the Sudan, most of the brick making kilns (intermittent scove kiln) have low combustion efficiencies (Hamid, 1994; BENS, 1996). Because of the high rates of incomplete combustion in the prevailing brick kilns of Sudan and the high GWPs of the products of incomplete combustion, biomass fuels may comprise even larger share of energy-related emissions when measured in terms of total GWP. Lefevre *et al.* (1997), FAO (1999) and WB (1998) have also considered collection of fuelwood from unsustainably managed forest is one of the major causes of deforestation and burning of biomass fuels is responsible for the emissions of both trace and non-trace greenhouse gases[4], such as CO_2, CH_4, CO, N_2O, NO_X and NO.

Therefore, the brick making industries in the Sudan act as a serious agent of deforestation and can be considered important sources of greenhouse gas emission as they use huge amount of fuelwood, comes from unsustainably managed forest and dung cake for brick burning with the brick kilns of low combustion efficiency.

MEPD/HCENR (2003), FAO (1999), BENS (1996), FNC (1995) and Hamid (1994) have documented the overall greenhouse gas emission in the Sudan within the general framework of estimation of greenhouse gas emission from fuelwood burning in African countries. Thus, the present study was carried out to explore the present status of biomass fuels consumption in the brick making industries of Sudan, as well as to assess the related rate of the emission of greenhouse gases and potential deforestation[5] caused by this sector.

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[4] Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic; those absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere (EPA, 2005; IPCC, 2005).

[5] Deforestation is defined as the conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold. Changes within the forest class, which negatively affect the stand or site, and thereby lower its capacity to supply products and/or services are termed as forest degradation (FAO, 1998a; FAO, 2001). For developed countries, deforestation is defined as change

Objectives of the study

The present study was carried out in the Sudan over a period of the three months from June to August 2005 to achieve the following objectives:

a) To visualize present status of biomass fuel (especially fuelwood and dung cake) consumption in the brick making industries of Sudan;
b) To estimate annual rate of potential deforestation caused by the surveyed brick making industries of Sudan due to the consumption of fuelwood;
c) To generate baseline information on how much greenhouse gases may emit in the atmosphere annually by the surveyed brick making industries of Sudan due to the burning of biomass fuels (fuelwood and dung cake);
d) To predict the annual maximum potential rate of deforestation caused by the brick making industries due to consumption of fuelwood in the Sudan;
e) To predict the annual rates of greenhouse gas emissions from brick making industries due to the consumption of fuelwood and dung cake in the Sudan.

of forest by reducing the tree crown cover to less than 20% and for developing countries - change of forest by reducing tree crown cover to less than 10% (FAO as cited in WMO, 2001).

2 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Brick making industries in the Sudan

2.1.1 General considerations

Brick making industries in the Sudan are mostly operated along the banks of the rivers during the dry season, October to July. Fired clay bricks are commonly used in most parts of Sudan. The total annual production of fired clay bricks in the Sudan is estimated to be about 2.8 billion. Of which, 88.5% production mainly concentrates on Khartoum and Central States (Gezira, Sinnar, White Nile and Blue Nile). Production on Blue Nile bank represents 82.4% and on River Nile bank is about 9.5% (Tab.1). Clay bricks are mainly produced by traditional methods where biomass fuels (fuelwood and dung cake) are used for brick burning. Modern brick production covers less than 2% of the total annual brick production where fuel oil is used. The total annual consumption of wood by the brick making industries of the Northern Sates of Sudan is found to be about 549,000 stacked m^3 equivalent to 183,000 t of fuelwood. Brick making industries of Khartoum and Central States consume 46.2% and 42.3% respectively, of the total annual consumption of wood in this sector. The consumption of wood per 1000 bricks varies widely from 0.117 m^3 to 1.6 m^3. Wood consumption per 1000 bricks in Kassala and Kordofan States is approximately more than 10 times that consumed in Khartoum and Central States. The total number of workers employed in this sector is about 35,000; of which 50% employed in Khartoum and 38% in Central States (Hamid, 1994; BENS, 1996).

Table 1. Brick making industries and their production rate along the river banks of Sudan

Location	No. of production units	Annual production of bricks ('000)	Production as % of total bricks production in Sudan
Blue Nile	1,347	2,281,280	82.5
River Nile	170	261,920	9.5
River Gash	28	39,200	1.4
River Atbara	26	36,600	1.3
Total	1,571	2,619,000	94.7

(Adapted from Hamid, 1994; Bilal, 2002)

2.1.2 Distribution of brick making industries in the Northern Sudan

Brick production in Sudan concentrates on Central Sudan which includes Khartoum, Central States and Southern part of Northern State. This area i.e. Central Sudan produces 75% of Northern Sudan's brick production. Production of fired clay bricks in Eastern State represents about 6% of brick production in Northern Sudan. Brick production units scatter along the banks of rivers El Gash in Kassala area and along River Adbara banks at Khashim El Gibra and El Showak areas. In Western Sudan, fired clay bricks production mainly concentrates on Kordofan and Darfur States and they produce 7% and 9% of Northern Sudan's brick production respectively. Brick production in Darfur State concentrates on Southern part of State around Niyala and Zalinga areas, whereas in Kordofan State, it scatters in valleys and Khors[6] such as Khor Taggat, Khor Bagarra and Khor Niwala in El Obeid area and Khor Abu Habil in Rahad, Um Ruwaba and Dilling areas (Hamid, 1994). FNC (1995) mentioned there are about 1,700 brick making industries in the Sudan but during the present study, the Brick Making Owners' Association in Khartoum State provided information[7] that there are about 650 brick factory owners and about 2,000 brick making industries in Khartoum state and the total number of brick making industries in the Sudan is approximately 3,450. It is also believed that a sizeable, but unknown number of unregistered smaller units are also scattered in rural areas meeting the local demand where required. Tab.2 shows the distribution of brick making industries in Northern Sudan:

Table 2. Distribution of brick making industries in the Northern Sudan

State/Province	Number of brick industries in 2005	Number of brick industries in 1994
Khartoum	2,000	800
Gezira, Central	800	
Sinnar, Central	110	654 (Central)
Ed Damazin (Blue Nile), Central	60	
Kordofan	100	58
Darfur	50	69
Kassala, Eastern	70	60
Northern State	260	63
Total	3,450	1,704

(Adapted and modified from Hamid, 1994)

[6] Khor: Seasonal streams usually bring sediments

[7] Information obtained from the association secretary, Mr Ali Ahmed Ibrahim (Appendix 2, Plate 12)

2.1.3 Raw materials of traditional fired clay bricks production

Clay is the basic raw material from which bricks are produced. Soil investigation reveals that the existing brick clays in Sudan as occur in nature are very different and widely vary in chemical composition and physical properties. To render them apt for brick making, suitable admixtures should be added and some technical treatment should be carried out. In prevailing traditional brick making, animal dung (*Zibala)* is the predominant additive, which acts as a leaning material and helps in both drying and firing. Sometimes sand is added besides animal dung, if the clay is of very high plasticity. In Western Sudan, sometimes groundnut shells are used for reasons of bulk availability at concentration ponds (oil mills). In Eastern Sudan sometimes, rotted bagasse is used instead of animal dung for the same above reasons (Hamid, 1994; Bilal, 2002). Tab. 3 shows the chemical composition of brick making clays in the Sudan.

Table 3. Chemical composition of brick making clays in the Sudan

Component	Location			
	Blue Nile (Gerif East)	River Nile (Kabashi)	While Nile (Guli)	El Obeid (Khor Taggat)
SiO_2	49.09	53.60	57.70	-
Al_2O_3	15.68	15.10	15.30	-
Fe_2O_3	10.07	13.10	7.88	-
CaO	6.32	3.40	2.50	1.51
MgO	2.52	1.60	1.90	-
Na_2O	2.10	-	2.90	-
K_2O	2.53	-	2.50	-
SO_3	-	-	0.13	-
TiO_2	1.65	-	-	-
Organic matter	-	-	-	0.25

(Adapted form Hamid, 1994)

2.1.4 Fired clay bricks production unit and their manufacturing process

Fired clay bricks production unit

There are wide variety of kiln types and sizes but they can be classified into two major groups: Intermittent and Continuous kilns. Further, intermittent kilns can be classified as clamp, scove, scotch and down draught kilns. The prevailing kiln type in the Sudan is the intermittent scove kiln (Appendix 1, Fig.2). It is a dense setting of bricks containing fuel, which is ignited at bottom and left to burn gradually until it reaches the other end. Tunnels are built at the base of the pile or setting. Through these tunnels fuelwood is fed. The width of a tunnel is 2-3 brick length equivalent to about 55 cm and they are separated by each other by 2 brick length. Green bricks above the tunnel are set in alternative courses. In Sudan the height is not more than 2 metre. Sometimes the other layer is built up from previously fired bricks to provide insulation and thus help in proper firing of the outer layer of green bricks. The top of the kiln is covered with 2 or 3 courses of fired bricks closely packed to give good insulation. The whole structure of the kiln is then plastered with wet mud mixed with animal dung or any other organic additive to reduce heat loss. Also sometimes the top of the kiln is covered with a layer of animal dung or any other organic matter which burns during firing and thus believed to help in firing underneath green bricks. Each kiln contains 70-100 thousands bricks, sometimes 120 thousands or more (Hamid, 1994; Bilal, 2002).

Traditional fired clay bricks production process (Hamid, 1994; BENS, 1996; Bilal, 2002)

Mixing**:** The clay is dug manually. The clay and an organic additive (mostly *Zibala*[8]) are mixed together and then water is added. The quantity of water required for moulding varies from place to place but it is about 30% on average. The mixing is carried out in a pit called mine. The mix is then thoroughly mixed by hoes and spades and afterwards by threading. It is then left for ageing for about 12 hours. Another mixing operation is carried out prior to brick moulding to brick shape (Appendix 1, Fig. 3; Appendix 2, Plate. 2).

Moulding**:** The most commonly used mould are steel and timber moulds, which are open at both top and bottom having two compartments. Each one is (210×100×55) mm to make a brick of size (190×100×50) mm. A mass from the prepared mix cut off and rolled up in a clot slightly exceeding the volume of the mould. The clay is then thrown with some force into the mould; the surplus shift is removed away by hand and demoulding takes place at drying platform (Appendix 1, Fig. 3; Appendix 2, Plate 3).

Drying**:** Drying of bricks is carried out under the sun. This entails leaving the freshly moulded bricks for about 24 hrs exposed to the sun, then turned over on edge and left for another 1-2 days to ensure uniform drying. Total drying period depends on the capacity of the kiln and daily output of green bricks. It is a common practice that the first moulded

[8] Zibala: A mix of animal dung and clay used for covering outside walls of mud buildings (Bilal, 2002)

batch undergoes a drying period of 18-25 days while last moulded batch takes 2-4 days (Appendix 1, Fig. 3; Appendix 2, plate 4).

***Firing*:** Firing consists of subjecting the green bricks to gradually increasing temperature up to a maximum of 700-900^{0}C depending on the fusion characteristics of clay. Firing of green bricks changes their physical and chemical structure. It renders them strong, durable and suitable for building construction (Appendix 1, Fig. 3; Appendix 2, Plate 6-7).

***Cooling*:** It is the period of time (usually about 10 days) during which the temperature of burnt units falls down and becomes safe and convenient to be removed from the kiln (Appendix 1. Fig. 3; Appendix 2, Plate 8).

2.1.5 Potentials of brick making industries as a source of greenhouse gases

Brickfields as an industrial venture bring easy money, but generally corrode the ecology and human health. Brickfields, with rapid urbanization are being indiscriminately developed throughout the country of Sudan. Fuelwood, which can also be a cheap fuel depending on its source, has been as a source of energy in brick making industry as is evident from FAO (2000), brick kilns were the highest consumers, consuming about 51.5% of the total industrial wood consumption in Sudan. Biomass burning is responsible for the emissions of trace and non-trace greenhouse gasses, such as CO_2, CH_4, CO, N_2O, NO_x and NO (WB, 1998). EBRD (2005) also mentioned that nitrogen oxides, carbon monoxide and carbon dioxide are emitted from the burning of hydrocarbon fuels in the brick making industries and from the effect of heat on clay, sulphur dioxides are also generated. So, brick making industries are important sources of greenhouse gases in the Sudan as they use huge quantity of fuelwood and considerable amount of dung cake for burning of bricks.

2.1.6 Brick making industries-agent of deforestation in the Sudan

The Forest Products Consumption Survey in the Sudan (FNC, 1995) reflects that the industrial sector in 1994 used only 6.8% of the total wood consumption. Its consumption was 1.07 million m^3 round wood. Almost all the quantity (98.5%) was consumed in the form of firewood and the remaining 1.5% is distributed among all the other uses. Brick kilns were the highest consumers, consuming about 51.5% of the total industrial wood consumption (FAO, 2000). The total annual brick production (2.8 billion) in the Sudan is mainly produced by traditional methods where fuelwood is used as main fuel for brick burning with exception in Khartoum area, dung cake (Appendix 2, Plate 11) is also used for firing of bricks. Therefore, fuelwood is the main fuel used in clay bricks firing. This means huge quantities of wood (about 549,000 stacked m^3 equivalent to 183,000 t of fuelwood) are used annually for clay brick production and accordingly forest resources are extensively exploited for this purpose. In other words, obviously brick making industries are acting as a serious agent of deforestation in the Sudan and this sector could be considered as one of the contributory factors that seriously affecting the environment (Hamid, 1994; BENS, 1996).

2.1.7 Instant impact of brick making industries' emissions on human body, agriculture and forestry

Impact on human body

The brick kilns emit toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of carbon monoxides and oxides of sulphur (SOx) that are harmful to eye, lungs, throat and also stunt the mental and physical growth of children (SOS-Arsenic.net, 2005). The recent scientific report states the combustion of clay and fuels for making bricks in the brickfields produces dioxins and furans as by-products, which first enter into the air from where the humans, birds and other animals either directly inhale or intake through different contaminated foodstuff both vegetable and animal origin. According to the Standard Toolkit prescribed by the United Nations Environment Programme (UNEP), under well-controlled processes 0.2 microgram TEQ (toxic equivalents) of dioxins and furans are emitted as by-product into the air during the production of each tonne of brick (Rahman, 2005).

Dioxins (polychlorinated di-benzo-para—dioxins) and furans (polychlorinated di-benzo-para—furans) are two groups of several chlorinated organic chemical molecules. Dioxins have 75 molecules (congeners) while furans have 135. All these together are also called dioxins. All these dioxins are chlorine rich, persistent for years together, self-transportable from one place/country to another, bio-accumulative because of their strong affinity for fats, and thus increase manifold through the food chain and cause harms to the host lives. Since they accumulate much in mothers' breast milk, the nursing infants' intake much more quantity of them. Since the dioxins are partially soluble in fats, they accumulate in fat-rich organs and tissues of humans particularly in breast, uterus, intestine of women, in testes and adipose tissues of men and other similar organisms. These are highly persistent and thus magnify manifold in those organs and as deadly elements cause several adverse effects. They cause abnormally functioning thyroids and other hormone system dysfunctions, feminization of males and masculinization of females, compromised immune systems, behavioural abnormalities, neurobehavioral impairment including learning disorders, a shortened period of lactation in nursing mothers, endometriosis, increased incidence of diabetes, tumours and cancers, and gross birth defects. The other effects include loss of appetite, weight loss, nausea, headache, liver and renal damage, cardiac arrhythmias, allergic conjunctivitis, blepharitis, and retinal angiopathy (Rahman, 2005).

Impact on agriculture and forestry

Brickfields' without the chimney and scrubber, emitted particles along with the carbon monoxide, sulphur dioxide and florin directly spread into the air and fall on the vegetation and crops of the locality. The layer of these particles close down the stomata, the pores on the leaves by which the plant inhales both carbon dioxide and oxygen respectively to carry out its photosynthesis process and respiration. If these processes remain inactive for a long time the plant itself may die. Department of Agriculture Extension (DAE) of Bangladesh, carried out a research to find out the impacts of brick making industries' emission on agriculture and forestry and found out the presence of the brickfields has made agriculture impossible in 2,000 acres of land in Savar area near Dhaka, the capital city of Bangladesh. Crop production has reduced from 70% - 80% in 3,000 acres affected by the emission of the gases from the brickfields. Pollination and rice formation processes in paddy are disturbed. As a result, the total rice production has decreased. Besides, sulphur dioxide reacting with the water vapour is producing sulphuric acid, which falls on the ground mixed with rain and dew. Consequently, the acidity of the soil will be increased turned the grass and crops yellow (SEHD, 1998).

2.1.8 Environmental impacts of brick making industries in the Sudan

According to Bilal (2002), fired clay brick making industries in the Sudan have following negative impacts on environment:

Air: Smoke and gases are emitted from burning of fuelwood used in firing and burning of the soil components. Volatile components are given off from the fired clay bricks and wood during firing. Smoke and heat that come out as a result of the burning process during day and night for a long time have an adverse effect on the vegetables and fruits produced along river banks. Dust presents a latent risk in the fired clay brick production particularly for the labour force. Fine quartz dust may cause silicosis[9]. Depending on the geological and meteorological conditions, dust may occur in clay mine pits during the extraction of the material. Dust raised by the movement of vehicles on unmade or dirty roadways on site or by the wind may be blown outside the site and cause nuisance or damage to property or vegetation

Soil: Since brick making is mainly concentrated along river banks, it causes erosion (*Haddams*) and damage to the arable lands in these areas. However, most of the lost arable lands are partly recovered annually after the flood period of the river by deposition of river sediments. In addition to this burnt clay soil is permanently destroyed and changed to an unrecoverable state.

Workplace: During firing of traditional brick kilns, temperature stresses on personnel are observed. There may be considerable exposure to heat when the wood is fed or while the fired red bricks are removed from kilns.

Ecosystem: On extracting clay for brick making, the landscape is impaired and there is an alternation to the surface. Since the raw materials requirement per kiln is not very high, the individual mining areas are generally relatively small. Nevertheless, removal of the soil in and around the mine destroys the local flora.

[9] Silicosis is an abnormal condition of the lungs caused by inhaling dust that contains silica which is a compound of silicon (Bilal, 2002).

Fuel energy: Many years ago brick kiln owners used to get their firewood stock from forests along river banks. Presently, the Savannah woodlands surrounding Khartoum and other major urban centres have shrunk by increased demand for fuel wood.

2.2 Deforestation and forest cover change

2.2.1 Global view of deforestation and forest cover change

Deforestation means those practices or processes that result in the conversion of forested lands for non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present (EPA, 2001). Deforestation, in recent years, has emerged as a central problem, both in Africa, Asia and in tropical forests all over the world. During the period of 1990-2000, the world annual forest cover change was 9.39 million ha (-0.2%). On a regional basis, during the same period, the annual forest cover change was: Africa, 5.26 million ha (-0.8%), Asia 0.36 million ha (-0.1%) and South America, 3.7 million ha (-0.4%) (FAO, 2005a). During the 1980s, the annual rate of tropical deforestation was 11.3 million ha (Lanly, 1982). The average annual rate of tropical deforestation during the decade of 1981-90 was 15.4 million ha (FAO, 1993).

2.2.2 Current state of forest resources and forest cover change in the Sudan

In 2000, the total forest coverage in Sudan was 61.63 million ha and which was 25.9% of the total land area of this country. During the same year annual forest cover change was 959,000 ha (-1.4%) (FAO, 2005a). Forest area in the Sudan was estimated by Jackson and Harrison (1958) to be between 36% and 43% of the total country area. Later in 1990, the forest resource assessment carried out by the FAO indicated that the forest cover had shrunk to 19% of the total country area. This was mainly attributed to expansion of agriculture, building and fuel wood production, and grazing. The most recent forest inventory (1995/1996) conducted for northern Sudan (between latitudes 10º and 16ºN by the Forests National Corporation (FNC), in cooperation with the FAO, estimated forest area at 12% in this part of the country (MEPD/HCENR, 2003).

The last forest inventory estimated the annual forest harvest (allowable cut) at 11.0 million cubic meters. While the 1994 forest products demand study conducted by the

FNC/FAO, estimated the total demand at 16.0 million cubic meters, this clearly indicates the annual loss in the forest capital (MEPD/HCENR, 2003).

2.3 Woodfuel production and consumption

2.3.1 Worldwide distribution of woodfuels production and consumption

Woodfuels consist of three main commodities: fuelwood, charcoal and black liquor. Fuelwood and charcoal are traditional forest products derived from the forest, trees outside forests, wood-processing industries and recycled wooden products from society. Black liquors are by-products of the pulp and paper industry. Quantification of the production and consumption of all forms of biomass fuel is invariably difficult, and woodfuels are no exception. In 1997, black liquor supplied about 72 MTOE of energy and woodfuels in total contributed about 540 MTOE annually to the world energy requirement. This amount is smaller than that of nuclear energy, which provided 650 MTOE in 1999, but substantially larger than the output from hydro and other renewable sources of energy. On average, the annual per-capita consumption of woodfuels is estimated to be 0.3-0.4 m^3 or around 0.1 TOE, but with considerable regional variances. In 1999, about 1.4 billion tonnes of fuelwood were produced worldwide, which is about 470 MTOE or about 5% of the world total energy requirement (WEC, 2005). Tab. 4 shows regional production of fuelwood (including wood for direct use as fuel and for conversion into charcoal) in 1999.

Table 4. Total Regional fuelwood production in 1999

Region	(MTOE)	Percentage (%)
Africa	141.1	29.9
North America	38.5	8.1
South America	37.7	8.0
Asia	216.1	45.8
Europe	34.9	7.4
Middle East	0.2	0.0
Oceania	3.8	0.8
Total World	472.3	100.0

(Adapted from WEC, 2005)

Asia is by far the largest producer and consumer of fuelwood, accounting for 46% of world production. Africa has the second highest share at 30%, followed by South America and North America, both at around 8%. On the other hand, the production and consumption of black liquor are concentrated in developed countries with large pulp and paper industries. Therefore, about 50% of black liquor consumption is in North America, followed by Europe with 19% and Asia with 12% (WEC, 2005).

Africa is the most intensive user of woodfuels in per-capita terms, with an average annual per-capita consumption of 0.77 m^3, or 0.18 TOE. In Africa, almost all countries rely on wood to meet basic energy needs. The share of woodfuels in African primary energy consumption is estimated at 60% to 86%, with the exception of North African countries and South Africa. On average, about 40% of the total energy requirement in Africa is met by fuelwood. In Asia, about 7% of the total energy requirement is met by fuelwood and the per-capita consumption level is not very high; however, the situation varies from country to country. Many countries in South and South East Asia, such as Nepal, Cambodia, Thailand and Indonesia, rely heavily on fuelwood, consuming more than 0.5 m^3 per-capita annually. In Europe and North America, the share of fuelwood in the total energy requirement is low, at 1.2% and 1.4% respectively. However, for countries such as Finland, Sweden, the USA and Canada, per-capita consumption is quite high if black liquor is included. In Austria, Finland and Sweden, wood energy provides about 12% to 18% of the country's total primary energy supply. In Latin America, about 10% of the total energy requirement is met by fuelwood (WEC, 2005).

2.3.2 Woodfuel as energy source in the Sudan

Biomass is a primary source of energy in Sudan like many other developing countries. Biomass contributed 78.5% of Sudan's total energy supply in 1995. In that year, 70.5% was in the form of woodfuel and only 8% was non-woody biomass. The other primary energy source is petroleum products, which contribute 19.4% of total energy supply. Hydro electricity contributes a tiny share of total energy supply, at just 2.1% (MEPD/HCENR, 2003).

Sudan depends mainly on forestry sector as energy source; it contributes a total of 4.11 million TOE representing 70.8% of energy supplies in the country. Demand for woodfuel increased in last years due to rapid population growth, urbanisation and shortage of modern energy. However, woodfuel consumption in Sudan is expected to decrease from current consumption as a result of investments and refining of petroleum by 2001 especially in household and traditional industries sectors. Fire wood consumption decreased by urbanisation, while firewood still dominates in rural areas. For traditional industries, including brick making, bakeries, oil mill etc. is found that woodfuel provides about 69.3% of their total consumption. Type of wood consumed is mainly firewood (stem), which had significant impact on forest resources. In commercial and service sectors include institutions such as schools, hospitals, restaurants, commercial establishments and informal activities (tea, *kisra*, etc), woodfuel consumption accounts 67% of the total energy used. It is concentrated in urban areas and their development depends on urbanisation rate. Quranic schools depend totally on wood fuel especially in lighting (FAO, 2000).

2.4 Energy sector in Sudan

2.4.1 Energy policies and strategies

Energy policy within the overall development policy of the National Comprehensive Strategy (1992-2002) has the following objective (MEM, 2000):

- To provide an adequate and reliable supply of energy from local resources to support sustainable development.
- To conserve the environment through efficient and optimal utilization of local resources, especially forests, and to promote tree planting activities. The solution of the energy problem should not be at the cost of the deterioration of natural resources.
- To conserve all energy types so as to generate the highest economic value for energy and minimize the cost to the economy.
- To develop the energy sector institutions to ensure coordination between consumers and producers.
- To develop and promote local and/ or adapted energy technologies particularly in the field of renewable energy resources.
- To train qualified and adequate staff at all levels to facilitate the development of energy sector.

2.4.2 Energy resources

Non-commercial resources includes fuelwood (which composed of fire wood and charcoal) beside agricultural residue and animal dung are utilized as fuel sources clearly dominating Sudan final energy consumption 66% and represent 78.6% from the energy supplies in 1997. According to the early 1970's landsite photo imagery, the total area and volume of Sudan's Forest resources to be about 1.08 million hectors and 1.96 million cubic meters respectively, about 70% of this is located in the Southern States and the forest area decrease towards the north of Sudan. Other biomass resource, agriculture waste (include crop residue which composed of cotton stocks, groundnut shells, bagasse and animal dung) is the most eligible sources for non-wood biomass energy. Renewable energy resources in Sudan include solar energy, wind energy, mini-hydro energy and geothermal energy (MEM, 2000).

2.4.3 Energy balance

In 1998, the estimated total energy supply was about 14,595 thousands TOE. Biomass (wood, animal waste) and the agriculture residues remained the major contributor with the share of 88% (83% wood and 5% residues). This is a clear indication of continuous exploitation of the country's forest resources. Petroleum and Hydro provided 11% and 1% respectively of the total energy supply (MEM, 2000; Tab. 5).

Table 5. Estimated energy supply in 1998

Resource	Supply (000 TOE)	Percentage (%)
Wood	12,152	83
Residues	798	5
Petroleum	1,555	11
Hydro	90	1
Total	14,595	100

(Adapted from MEM, 2000)

On the other hand, consumption estimates during the same period was about 7,790 thousand TOE (Tab. 6). The difference between supply and consumption is 6,805 thousands TOE (46.6%), which reflects the losses and the low efficiency of utilization of energy resources about 53.4%. The most of the losses occurring in the process of converting wood to charcoal where more than 6.4 million TOE has been lost (MEM, 2000).

Table 6. Estimated energy consumption by sector in 1998 (000 TOE)

Sector	Household	Services	Transport	Industry	Agriculture	Total
Petroleum	22	69	694	177	180	1,142
Electricity	53	33	-	27	3	116
Wood	2,522	691	-	217	-	3,430
Charcoal	2,150	154	-	-	-	2,304
Agriculture residue	641	-	-	157	-	798
Total	5,388	947	694	578	183	7,790
%	69	12	9	8	2	100

(Adapted from MEM, 2000)

On sectoral basis, household sector is the largest consuming sector with the largest share, 5,388 thousands TOE (69%). Services sector consumed 947 thousands TOE, which is 12% of the total national energy consumption. The transportation sector consumed 694 thousands TOE of the total energy consumption in 1998 and all of it in the form of petroleum products. It absorbed more than 60% of the total petroleum consumed in 1998. The industrial sector consumed only 578 thousands TOE (8%) of the total energy consumption during the same year. It consumed only 6% of the total biomass and 15% of the total petroleum consumption and 23% of the total electricity. The agriculture sector consumed only 183 thousands TOE (2%) of the total country energy consumption in 1998 (Tab. 6). Most of the consumption (98%) was petroleum products for water lifting in agricultural operations. The rest (2%) is electricity, which is used for water lifting only (MEM, 2000).

2.5 General information about emission of greenhouse gases, their sinks and sources, regional status of emission and international initiatives to reduce global rate of emission

2.5.1 Greenhouse gases and greenhouse effect

Greenhouse gases: Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic; those absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planetary surface. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Besides CO_2, N_2O, and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) (EPA, 2005; IPCC, 2005). According to IPCC (1996), emissions of greenhouse gases (GHGs) from human activities as a primary cause for global climate change. The primary anthropogenic (human-induced) GHGs include: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); ozone (O_3); carbon monoxide (CO); nitrogen oxide (NO_X); non-methane hydrocarbons (NMHCs); and a variety of manufactured aerosols that do not occur in nature, primarily chlorofluorocarbons (CFCs).

Greenhouse effect: Greenhouse effect is the natural mechanism of trapping and build-up of heat in the lower atmosphere near to planet's surface. Some of the heat flowing back towards space from the earth's surface is absorbed by water vapour, carbon dioxide, methane and other gases in the atmosphere. If the atmospheric concentrations of these gases rise, then theory predicts that the average temperature of the lower atmosphere will gradually increase. Without the greenhouse effect we would be living in a very chilly place, the world's average temperature would be minus 18°C, instead of the 16°C we are used to. Current life on earth could not be sustained without the natural greenhouse effect. The natural greenhouse effect is a phenomenon created by the heat energy radiated by the sun and greenhouse gases normally present in the atmosphere. In simple terms, sunlight passes through the atmosphere, warming the earth. In turn, the earth radiates this energy back towards space. As it passes through the atmosphere, greenhouse gases (water vapour, carbon dioxide, methane and nitrous oxide) absorb part of the energy, while the remainder escapes into space. This means that some of the sun's energy becomes trapped, thus making the lower part of the atmosphere and the earth, warmer. The enhanced greenhouse effect is an increase in the natural process of the greenhouse effect, brought about by human activities, whereby greenhouse gases such as carbon dioxide, methane, chlorofluorocarbons and nitrous oxide are being released into the atmosphere at a far greater rate than would occur through natural processes. Global warming is one of the consequences of the enhanced greenhouse effect and will cause worldwide changes to climate patterns (EPA, 2005; IPCC, 2005; AAS, 2005).

2.5.2 Sources and sinks of greenhouse gases

Most of the greenhouse gases have both natural and anthropogenic (human-made) emission sources and there are significant natural mechanisms (land-based or ocean based sinks) for removing them from the atmosphere. However, increased levels of anthropogenic emissions have pushed the total level of greenhouse gas emissions (both natural and anthropogenic) above the natural absorption rates for these gases. This positive imbalance between emissions and absorption has resulted in the continuing growth in atmospheric concentrations of these gases. Tab. 7 illustrates the relationship between anthropogenic and natural emissions and absorption of the principal greenhouse gases on an annual average basis during the 1990s (EIA, 2004).

Table 7. Global natural and anthropogenic sources and absorption of greenhouse gases in the 1990s

Gas (in million metric tons)	Sources			Absorption	Annual increase in gas in the atmosphere
	Natural	Anthropogenic	Total		
CO_2	770,000	23,100	793,100	781,400	11,700
CH_4	239	359	598	576	22
N_2O	9.5	6.9	16.4	12.6	3.8

(Adapted from IPCC, 2001; EIA, 2004)

The exhibit (Fig. 4) shows that the primary sources of anthropogenic GHGs are: fossil fuel consumption, land-use change, non-fossil based methane and cement manufacturing. Broadly, the principal sources of greenhouse gases are energy sector (fuel combustion and fugitive emissions), industrial processes, agricultural sector, land use change and forestry and biomass burning (Tab. 8-9; UNFCCC, 2005a). NET (2000) estimated in 1990, globally agricultural sector emitted highest CO_2 (39.82%) in the atmosphere followed by energy sector (29.43%), land use change and forestry (27.41%) and industrial processes (2.07%). UNFCCC (2005a) revealed that among the Annex I Party[10] countries, the main sources of greenhouse gases (measured in Gg[11] of CO_2 equivalent) in 2002 were fuel combustion (12,082,381 Gg) followed by agriculture (1,241,440 Gg), industrial processes (821,592 Gg) and fugitive emissions (533,142 Gg) (Tab. 8). Whereas, in 1994,

[10] **Annex I Party:** Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States of America.

[11] 1 Gg (Gigagram) = 10^9 grams = 1,000 t (MT, metric tons)

among the Non-Annex I Party[12] countries, the major sources were fuel combustion (2,061,153 Gg) followed by agriculture (1,196,557 Gg), land-use change & forestry (1,139,516 Gg) and biomass burning (490,588 Gg) (Tab. 9).

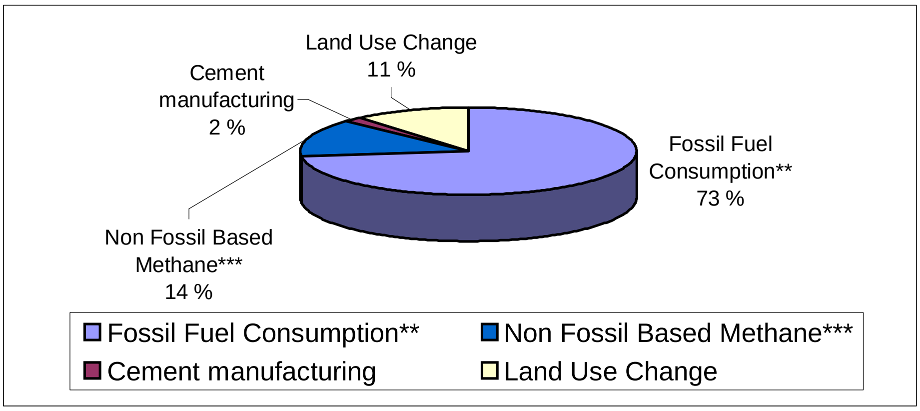

Figure 4. Sources of greenhouse gas emissions covered under the UNFCCC, 1991* (CDIAC, 1995)

* Greenhouse gas emissions covered under the UNFCCC do not include CFCs.
** Fossil fuel consumption includes the global warming potential of methane from oil and gas production and coal mining.
*** Non-fossil based methane includes solid waste, wet rice, agriculture and livestock.

[12] **Non-Annex I Party:** Albania, Algeria, Antigua and Barbuda, Argentina, Armenia, Azerbaijan,, Bahamas Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Botswana, Burkina Faso, Burundi, Cambodia, Cape Verde, Chad, Chile, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Cote d Ivoire, Cuba, D. Rep. of Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guyana, Haiti, Honduras, Indonesia, Iran (Islamic Rep. of), Israel, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kyrgyzstan, Lao Peop Dem Rep, Lebanon, Lesotho, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Micronesia (Fed. States of), Mongolia, Morocco, Namibia, Nauru, Nicaragua, Niger, Niue, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Republic of Korea, Republic of Moldova, Saint Kitts and Nevis, Saint Lucia, Samoa, Senegal, Seychelles, Singapore, Solomon Islands, Sri Lanka, St. Vincent and the Grenadines, Swaziland, Tajikistan, Thailand, The f.Y. Rep of Macedonia, Togo, Trinidad and Tobago, Tunisia, Turkmenistan, Tuvalu, Uganda, Uruguay, Uzbekistan, Vanuatu, Yemen, Zimbabwe.

Table 8. Greenhouse gas emission in 2002 by Annex I Party according to sources

Sources & Sink	CO_2 (in Gg)	CH_4 (in Gg of CO_2 equivalent)	N_2O (in Gg of CO_2 equivalent)	CO (in Gg of CO_2 equivalent)	NOx (in Gg of CO_2 equivalent)	SO_2 (in Gg of CO_2 equivalent)	NMVOC (in Gg of CO_2 equivalent)	HFCs (in Gg of CO_2 equivalent)	PFCs (in Gg of CO_2 equivalent)	SF_6 (in Gg of CO_2 equivalent)	Total (in Gg of CO_2 equivalent)
Fuel combustion	11,682,210	37,129	162,617	129,090	35,147	22,405	13,783	-	-	-	12,082,381
Fugitive emissions	55,338	474,964	80	274	160	500	1,826	-	-	-	533,142
Industrial processes	474,166	5,437	80,299	4,943	887	3,326	3,133	181,126	32,363	35,912	821,592
Solvent & other product use	5,707	-	9,350	51	3	0.95	9,530	-	-	-	24,642
Agriculture	1,525	553,061	663,060	20,281	1,632	0.02	1,881	-	-	-	1,241,440
Land-use change & Forestry	-987,008	7,953	4,289	7,137	147	0.12	2,463	-	-	-	21,989
Waste	32,340	415,747	32,816	855	123	53	256	-	-	-	482,190
Other	720	38	1,184	19	3	0.02	-	-	-	-	1,964
Total	12,252,006	1,494,329	953,695	162,650	38,102	26,285	32,872	181,126	32,363	35,912	15,209,340

(Adapted and modified from UNFCCC, 2005a)

Table 9. Greenhouse gas emission in 1994 by Non-Annex I Party according to sources

Sources	CO_2 (in Gg)	CH_4 (in Gg of CO_2 equivalent)	N_2O (in Gg of CO_2 equivalent)	CO (in Gg of CO_2 equivalent)	NO_X (in Gg of CO_2 equivalent)	SO_2 (in Gg of CO_2 equivalent)	NMVOC (in Gg of CO_2 equivalent)	Total (in Gg of CO_2 equivalent)
Biomass burning	488,364	1,469	183	561	11	-	-	490,588
Fuel combustion	1,940,101	45,201	19,826	41,402	5,681	4,726	4,216	2,061,153
Fugitive emissions	40,796	195,060	-	579	6	105	164	236,710
Industrial processes	133,854	592	3,881	231	113	1,935	4,659	145,265
Solvent & other product use	4	-	-	-	-	-	100	104
Agriculture	701	618,879	451,658	116,616	8,700	-	3	1,196,557
Land-use change & Forestry	1,078,244	40,507	4,451	15,812	451	-	51	1,139,516
Waste	152	156,575	7,691	-	-	-	-	164,418
Other	-	195	-	65	0.09	9	16	285
Total	3,682,216	1,058,478	487,690	175,266	14,962	6,775	9,209	5,434,596

(Adapted and modified from UNFCCC, 2005a)

2.5.3 Regional status of greenhouse gas (CO_2) emission in a global perspective

Carbon dioxide emissions for the industrialized world (North America, Western Europe, and Industrialized Asia) in 2001 were estimated at 11,634 million metric tons, or about 49% of the world total, implying that U.S. emissions represent about 49% of the energy related carbon dioxide emissions from the industrialized world. The remaining 51% of 2001 worldwide energy related carbon dioxide emissions come from developing countries (9,118 million metric tons) and the former Soviet Union and Eastern Europe (3,147 million metric tons). Remarkably, during the same year among all the continents, Central & South America and Africa had the lowest shares of total global CO_2 emission, 964 and 843 million metric tons respectively (Tab.10; EIA, 2004). EIA (2004) also reported that the five leading countries of CO_2 emission in 2001 were the USA, China, Russia, Japan, and India and these countries emitted 5,692; 3,050; 1,614; 1,158 and 917 million metric tons of CO_2 respectively in the atmosphere.

Table 10. World carbon dioxide (CO_2) emissions by region, 1990-2025 (in million metric tons)

Region	History			Projections				Avg. Annual % Change, 2001-2025
	1990	2000	2001	2010	2015	2020	2025	
North America[A]	5,769	6,731	6,613	7,677	8,255	8,876	9,659	1.6
Western Europe[B]	3,412	3,442	3,465	3,567	3,682	3,832	4,022	0.6
Industrialized Asia[C]	1,280	1,526	1,556	1,694	1,770	1,840	1,962	1.0
Total Industrialized	10,462	11,699	11,634	12,938	13,708	14,548	15,643	1.2
Former Soviet Union[D]	3,798	2,338	2,399	2,600	2,840	3,118	3,393	1.5
Eastern Europe	1,104	756	748	797	827	888	920	0.9
Total FSU/EE	4,902	3,094	3,147	3,397	3,667	4,006	4,313	1.3
Developing Asia[E]	3,994	5,709	6,012	7,647	8,863	10,240	11,801	2.9
Middle East[F]	846	1,262	1,299	1,566	1,729	1,910	2,110	2.0
Africa	656	811	843	971	1,110	1,259	1,413	2.2
Central & South America[G]	703	961	964	1,194	1,358	1,578	1,845	2.7
Total Developing	6,200	8,744	9,118	11,379	13,060	14,987	17,168	2.7
Total World	21,563	23,536	23,899	27,715	30,435	33,541	37,124	1.9

(Adapted and modified from EIA, 2004)

[A] United States, Canada and Mexico
[B] United Kingdom, France, Germany, Italy, Netherlands and other Western Europe
[C] Japan, Australia/New Zealand
[D] Russia and other FSU (Former Soviet Union)
[E] China, India, South Korea and other Asia
[F] Turkey and other Middle East
[G] Brazil and other Central/South America

2.5.4 Greenhouse gas emission in the Sudan

The results of Sudan's national inventory indicated that the total emissions of greenhouse gases for 1995 amount to about 25,750 Gg. The main gas emitted is CO_2 (20,077 Gg) which constitutes more the 75% of the 1995 total, followed by CO (3,280 Gg), CH_4 (1,985 Gg), small amount of other gases such as NMVOC, NO_X, N_2O, and insignificant amounts of HFCs and SO_2. Land-use change and forestry, though it should constitute a sink, was found to be the main emitter of CO_2, with 15,577 Gg, or more than 75% of total CO_2 emitted. In the energy sector, CO_2 emissions from fossil fuel are estimated at 4,328 Gg-about 22% of the CO_2 total. The energy sector emits the major share of CO and NMVOC (2,104 and 263 Gg respectively). Biomass energy is estimated to emit about 21,936 Gg of CO_2, constituting more than 80% of total CO_2 emitted in the energy sector. Agriculture is the dominant sector in CH_4 emissions, estimated at 1,713 Gg, or more than 86% of total CH_4 emissions in Sudan (Tab. 11; MEPD/HCENR, 2003).

GHGs can be expressed as CO_2 equivalent. Tab. 11 shows the assumed GWP values used in calculating GHG emissions in terms of Gg of carbon equivalent. CO_2 is the most important greenhouse gas, responsible for about 60% of the enhanced greenhouse effect. In 1995, the total global carbon emitted from energy activities was estimated at 6 billion metric tons. Sudan's contribution to this was very modest, even in comparison to many other developing countries. The 1995 per capita emission of CO_2, as an example, is only 0.003 Gg per person (i.e., 89,220 Gg/28.7 million people) (MEPD/HCENR, 2003).

Table 11. Greenhouse gas emission in the Sudan in 1995 (in Gg)

Source and Sink	Total CO_2 - equivalent	Net CO_2 emitted	CH_4	N_2O	NO_X	CO	NMVOC
Energy	16,706	4,328	150	1	58	2,104	263
Industrial processes	173	173	0	-	0	0	11
Agriculture	50,083	0	1,713	30	16	388	0
Land-use change & forestry	21,184	15,577	90	1	22	787	0
Waste	1,055	0	33	1	0	0	0
Total emission & removals	89,220	20,077	1,985	33	97	3,280	274
Emissions from biomass energy[13]	21,936	21,936	0	0	0	0	0

(Adapted from MEPD/HCENR, 2003)

[13] Emissions from biomass energy are not added to total energy emissions, however, to avoid double counting; biomass is accounted for, instead, in the land-use change and forestry sector.

2.5.5 Emissions from biomass fuel burning

Biomass fuel is in any fuel that derives from biomass-recently living organism or their metabolic by-products, such as manure from cows. There are many forms of solid biomass that are combustible as a fuel, e.g. wood, straw and other dried plants, animal waste, husks or shells from crops and bagasse. Burning of biomass fuels is responsible for the emissions of both trace and non-trace greenhouse gases, such as CO_2, CH_4, CO, N_2O, NO_X and NO Combustion of biomass plays a significant role in global atmospheric chemistry due to the non-CO_2 trace gases and its potential for global warming due to an enhanced greenhouse gas effect. However, much of the CO_2 from the biomass does not result in a net increase in atmospheric concentration because the plants absorb it during photosynthesis. The accurate estimation of greenhouse gas emission from biomass fuel burning in small combustion is important to know their significance and to suggest suitable mitigation options (WB, 1998; ITDG, 2005).

2.5.6 International initiative on the reduction of the emissions of greenhouse gases

The Kyoto Protocol aims to address the problem of anthropogenic climate change. The Protocol, adopted on 11 December 1997, complements the 1992 UN Framework Convention on Climate Change. In this Convention, countries agreed to aim to reduce greenhouse gas emissions. The Kyoto Protocol is the legally binding international agreement under which industrialized countries are supposed to reduce their collective emissions of six greenhouse gases by 5.2% by 2008-12, calculated as an average over these five years. In order to help industrialized countries to reduce their emissions in a cost-effective way, three flexible “mechanisms” were included in Kyoto Protocol (a) The clean development mechanism (CDM): Creation of certified emission reductions through investments in developing countries regulated by a newly formed authority (b) An emission trading regime: A country exceeding its emission reduction goal can sell the excess to another that has not reached its goal and (c) A joint implementation: Creation of emission reduction units derived from investments between parties. Each country is expected either to reduce its emissions or to purchase quota from other countries so that the sum of these two is not more than its national emission limit. This Protocol also considered funding, technology transfer, and the review of information under the convention. The Kyoto Protocol is only a first step in tackling the problem of climate change. Achieving the Kyoto targets will only reduce developed country emissions by

5.2%. However, any reduction in greenhouse gas emissions will mark a significant transformation considering the persistent upward trend in emissions since the Industrial Revolution. As of February 16, 2005, 141 nations had ratified the Kyoto Protocol and this Protocol came into force on 16 February, 2005 (WMO/UNEP, 1996; UNFCCC, 2005b).

2.6 Global warming and its impact on climate change

2.6.1 Global warming and global warming potential

Global warming is the progressive gradual rise of the temperature of the earth's surface thought to be caused by the greenhouse effect and responsible for changes in global climate patterns. It has occurred in the distant past as the result of natural influences, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases. The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a period of time (usually 100 years). Gases involved in complex atmospheric chemical processes have not been assigned GWPs (EPA, 2001). CO_2, CH_4 and N_2O account for over 90% of the global warming potential (GWP) of all GHGs emissions. In order to compare the climate change impacts of these three primary GHGs, the IPCCs GWP index for a 100-year time horizon was utilized. The GWP indices for the three primary GHGs are: CO_2 = 1, CH_4 = 21 and N_2O = 310. By applying the appropriate GWPs, the total GHGs emissions of a country can be expressed in CO_2-equivalent. For example, one tonne of CH_4 would be equivalent to 21 tonnes of CO_2. Similarly, one tonne of N_2O would be equivalent to 310 tonnes of CO_2 (ALGAS, 1998).

2.6.2 Climate change

Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of natural activity. This usage differs from that in the UNFCCC, where climate change refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods (IPCC, 2001; RWEDP, 2000).

2.6.3 Worldwide impact of global warming

Projected climate variability and change

IPCC (1996) indicates that an increase in the mean global temperature of 2^0c over the 21st century is likely, potentially resulting in a sea level rise of as much as one meter, increased inundation of coastal areas, higher frequency of flooding and more intense storms whereas EPA (2000) expects that the average global surface temperature could rise 1-4.5°F (0.6-2.5°C) in the next fifty years, and 2.2-10°F (1.4-5.8°C) in the next century, with significant regional variation. Evaporation[14] will increase as the climate warms, which will increase average global precipitation. Soil moisture is likely to decline in many regions, and intense rainstorms are likely to become more frequent.

According to the most recent report of IPCC, the globally averaged surface temperature is projected to increase by 1.4 to 5.8^0C over the period 1990 to 2100 and global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 to 2100 due to thermal expansion and loss of mass from glaciers and ice caps. By the second half of the 21st century, it is likely[15] that precipitation will have increased over northern mid to high latitudes and Antarctica in winter and at low latitudes there are both regional increases and decreases over land areas. It is also likely[15] that warming associated with increasing greenhouse gas concentrations will cause an increase of Asian summer monsoon precipitation variability. Moreover, global warming is likely[15] to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño[16] events in many different regions (IPCC, 2001).

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[14] Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation (FAO, 1998b).

[15] Likely: 66-90% chance.

[16] El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific, having important consequences for weather around the globe (NOAA, 2005).

Observed climate variability and change

Average global surface temperature has increased by approximately 0.6^0C since the late 19th century. Globally, it is very likely[17] that the 1990s was the warmest decade and 1998 the warmest year since 1861. Since the late 1950s the overall global temperature increases in the lowest 8 kilometres of the atmosphere and in surface temperature have been similar at 0.1^0C. It is very likely that[17] precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid and high latitudes of the Northern Hemisphere continents and it is likely[15] that rainfall has increased by 0.2 to 0.3% per decade over the tropical (10^0 N to 10^0 S) land areas. It is also likely[15] that rainfall has decreased over much of the Northern Hemisphere sub-tropical (10^0 N to 30^0 N) land areas during the 20th century by about 0.3% per decade (EPA, 2000; IPCC, 2001). According to Tide gauge data, IPCC (2001) estimated that global average sea level rose between 0.1 and 0.2 metres during the 20th century whereas EPA (2000) reported that it was 4-8 inches over the past century.

Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities. About three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years is due to fossil fuel burning and the rest is predominantly due to land-use change, especially deforestation. Since 1750, the atmospheric concentration of CO_2 has increased by 31%, CH_4 by 151%, N_2O by 17%, and O_3 by 36%. In addition, CO emissions have recently been identified as a cause of increasing CH_4 concentration (IPCC, 2001).

2.6.4 African climate trends and projections

Africa is highly vulnerable to global climate change. Impacts of particular concern to Africa are related to water resources, food production, human health, desertification, and costal zones especially in relation to extreme events. Alternation of spatial and temporal pattern of temperature i.e. global greenhouse effect, rainfall, solar radiation and winds from a changing climate will exacerbate desertification. Desertification is a critical threat to sustainable resource management in arid, semi-arid and dry sub humid regions of Africa, undermining food and water security (IPCC/WMO/UNEP, 1998).

With respect to temperature, land areas may warm by 2050 by as much as 1.6°C over the Sahara and semi-arid parts of southern Africa (Hernes *et al*., 1995; Ringius *et al*., 1996).

[17] Very likely: 90-99% chance

Equatorial countries (Cameroon, Uganda, and Kenya) might be about 1.4°C warmer. This projection represents a rate of warming to 2050 of about 0.2°C per decade. Sea-surface temperatures in the open tropical oceans surrounding Africa will rise by less than the global average (i.e., only about 0.6-0.8°C); the coastal regions of the continent therefore will warm more slowly than the continental interior (IPCC/WMO/UNEP, 1998).

In general, rainfall is projected to increase over the continent-the exceptions being southern Africa and parts of the Horn of Africa; here, rainfall is projected to decline by 2050 by about 10%. Parts of the Sahel could experience rainfall increases of as much as 15% over the 1961-90 average. Equatorial Africa could experience a small (5%) increase in rainfall (IPCC/WMO/UNEP, 1998).

Projected temperature increases are likely to lead to increased open water and soil/plant evaporation. As a rough estimate, potential evapotranspiration[18] over Africa is projected to increase by 5-10% by 2050. Rainfall may well become more intense, but whether there will be more tropical cyclones or a changed frequency of El Niño events remains largely in the realm of speculation (IPCC/WMO/UNEP, 1998). Changes in sea level and climate in Africa might be expected by the year 2050; Hernes *et al*. (1995) project a sea-level rise of about 25 cm.

According to the UNFCCC, "countries with arid and semi-arid areas or areas liable to floods, drought and desertification are particularly vulnerable to the adverse effects of climate change." Scientists cannot yet predict how rising atmospheric levels of greenhouse gases will affect the global rate of desertification. What they can predict is that changes in temperature, evaporation, and rainfall will vary from region to region. As a result, desertification is likely to be aggravated in some critical areas but eased in other places (UNCCD, 2005).

Although the significance of future global warming for dryland climates cannot be assessed with confidence, predictions based on general circulation models suggest

[18] Evapotranspiration: Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (FAO, 1998b).

temperatures will rise in all dryland regions in all seasons. Predicted increases in temperature are expected to increase potential evapotranspiration rates in drylands and, without large increases in precipitation, many drylands could become more arid in the coming century. Thus, UNEP warns that for inhabitants of drylands, the message is clear: global warming is likely to further reduce the already limited availability of moisture (White and Nackoney, 2003).

Relatively little research has been conducted on the possible impact of climate change on deserts. Today, deserts tend to be found at latitudes between 20 and 32 degrees. Soils are extremely dry at these latitudes because the potential for evaporation and transpiration is generally greater than the average rainfall. If global temperatures were to rise by 4°C, the potential evapotranspiration would increase 30-40%, while precipitation would only increase 10-15%. As a result, the area with a deficiency of precipitation would expand pole ward and toward the equator. Studies that focus on what is likely to occur over the next century, however, do not indicate whether deserts are more likely to expand or contract. Studies using the bio-geographic models have estimated that desert shrub lands could increase by as much as 185% or decrease by as much as 56% (EPA, 2000).

2.6.5 Vulnerability to global climate change in Africa

Several climate regimes characterize the African continent; the wet tropical, dry tropical and alternating wet and dry climates are most common. The African continent is particularly vulnerable to the impacts of climate change because of widespread poverty, recurrent droughts, inequitable land distribution and over dependence on rain-fed agriculture. IPCC/WMO/UNEP (1997) has summarized the potential impacts of global climate change in African continent under the following heads:

Ecosystems: A sustained increase in mean ambient temperatures beyond 1^0C would cause significant changes in forest and range-land cover; species distribution, composition and migration patterns and biome distribution. Arid to semi-arid sub-regions and grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable.

Hydrology and water resources: Of the 19 countries around the world currently classified as water-stressed, more are in Africa than in any other region. A reduction in precipitation projected by some General Circulation Models (GCMs) for the Sahel and southern Africa-if accompanied by high inter-annual variability-could be detrimental to the hydrological balance of the continent and disrupt various water dependent socio-economic activities. A drop in water level in dams and rivers could adversely affect the quality of water by increasing the concentrations of sewage waste and industrial effluents, thereby increasing the potential for the outbreak of diseases and reducing the quality and quantity of fresh water available for domestic use.

Agriculture and food security: Agriculture is the economic mainstay in most African countries excluding oil-exporting countries, contributing 20-30% of GDP in sub-Saharan Africa and 55% of the total value of African exports. In most African countries, farming depends entirely on the quality of the rainy season-a situation that makes Africa particularly vulnerable to climate change. A rise in mean winter temperatures also would be harmful to the production of winter wheat and fruits that need the winter chill. Productivity of freshwater fisheries may increase, although the mix fish species could be altered.

Coastal systems: The coastal nations of west and central Africa (e.g. Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, and Angola) have low-lying lagoonal coasts that are susceptible to erosion and threatened by sea-level rise, particularly because most of the countries in this area have major and rapidly expanding cities on the coast. The west coast often is buffeted by storm surges and currently is at risk from erosion, inundation and extreme storm events. The coastal zone of east Africa also will be affected, although this area experiences calm conditions through much of the year. However, sea level rise and climatic variation may reduce the buffer effect of coral and patch reefs along the east coast, increasing the potential for erosion. Studies also indicate that a sizeable proportion of the northern part of the Nile delta will be lost through a combination of inundation and erosion with consequent loss of agricultural land and urban areas.

Human health: Africa is expected to be at risk primarily from increased incidences of vector-borne diseases and reduced nutritional status. A warmer environment could open up new areas for malaria; altered temperature and rainfall patterns also could increase the incidence of yellow fever, dengue fever, onchocerciasis and trypanosomiasis.

Tourism and wildlife: Tourism, one of Africa's fastest growing industries, which is based on wildlife, nature reserves, coastal resorts and an abundant water supply for recreation. Projected droughts and/or reduction in precipitation in the Sahel and eastern and southern Africa would devastate wildlife and reduce the attractiveness of some nature reserves, thereby reducing income from current vast investments in tourism.

2.6.6 Vulnerability to climate change in the Sudan

MEPD/HCENR (2003) has illuminated the potential impacts of climate change in the Sudan based on a combination of tools namely, three GCMs[19], IPCC emission scenarios (IS92a), scenario generating software (MAGICC/SCENGEN version 2.4) and linear interpolation techniques. To foresee climate change scenarios, the data collected from five stations (El Obeid, En Nahud, Rashad, Kadugli and Babanusa) of Kordofan region which is located in mid-western Sudan between latitudes $9^{0}30^{/}$ and $16^{0}24^{/}$ North and longitudes 27^{0} to 32^{0} East. Kordofan region ranges across desert and semi-desert in the North, to moist, sub-humid and rich savannah in the South. Arid and semi-arid zones make up the largest segment of Kordofan's land area and the data collected at these stations tells a story of a varied regional climate. However, climate change scenarios can be summarized on the critically important sector of Sudan as follows:

Agriculture and forestry: The recent droughts, socio-economic changes, and on-going process of desertification have drastically affected the distribution and condition of tree cover in the gum arabic belt and agricultural crops in the Kordofan region, particularly in the sandy areas of North Kordofan and North Darfur. Approach one[20] and approach two[21] of climate change scenarios suggested that this sector and the nation as a whole- may be hard hit by even modest changes in temperature and precipitation, and found out following specific impacts for this sector-(i) reduction in ecosystem integrity and resilience and a decline in biodiversity (ii) decrease in forest area and area under cultivation (iii) the humid agro climatic zones shift southward, rendering areas of the North increasingly unsustainable for agriculture (iv) decline in crop production (29-71%

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[19] General Circulation Models (GCMs) are mathematical representations of atmosphere, ocean, ice cap and land surface processes based on physical laws and empirical relations (UNEP, 1998)

[20] MAGICC/ SCENGEN software, version 2.4, with input from the IS92A emission scenarios, and three General Circulation Models (HADCM2, BMRC and GFDL) (MEPD/HCENR, 2003).

[21] Synthetic vulnerability scenarios (scenarios comprised of assumption based, incremental temperature and precipitation changes (MEPD/HCENR, 2003).

or sorghum, 15-62% for millet) and gum yield (25-30%) (v) the northern, western and south-western parts of the region are found to be highly sensitive to the rise in temperature.

Malaria: World Health Organization reported that almost 300 million cases of malaria occur each year and over one million people die, with risk particularly high in Sub-Saharan Africa, where about 90% of deaths occur due to malaria. Climate change is expected to exacerbate the current problem. The projected increase in transmission potential suggests that the changes in temperature and precipitation anticipated under climate change could adversely alter the current distribution and intensity of malaria incidence in Sudan and people could be exposed to significantly increased risk of malaria. In addition to the potential human toll, socioeconomic impacts such as the increased burden on the nation's health care system may be significant.

Water resources: The availability of water in Sudan, an extremely arid country, is a perennially critical issue. Many areas have no permanent surface water and must rely entirely on seasonal rainfall and groundwater. The water assessment shows that soil moisture declines under future climate change conditions. Water consumption, population growth, high variation in rainfall and the high rate of evaporation (due to the rise in temperature) are predicted to lead to a situation of water crisis. The results also suggests that in the northern parts of the region, the soil moisture deficit could be equivalent to the water holding capacity of the soil in 2060-a situation of extreme water stress.

3 MATERIAL AND METHODS OF FIELD SURVEY

3.1 Study area

3.1.1 Location

The Sudan lies within the tropical zone between latitudes 3^0 and 20^0 North and longitudes 22^0 and 38^0 East. The country is bounded on the east by the Red Sea and on other sides by nine African countries: Eritrea and Ethiopia to the East; Kenya, Uganda and the republic of the Congo to the South; the Central African Republic and Chad to the West and Libya and Egypt to the North. It is divided administratively into 26 States. Of which four administrative States are purposively selected for the present study namely Khartoum, Kassala, Gezira and the White Nile (FAO, 2000; MEM, 2000; MEPD/HCENR, 2003; Fig. 5).

3.1.2 Climatic condition

Sudan is divided into five climatic zones i.e. desert, semi-desert, savannah, maritime and equatorial. It can be described as tropical, varying from desert climate in the North to regions with semi-desert characteristics, to continental equatorial climate in the South. Rainfall varies from less than 75 mm in the desert, 75 mm to 300 mm in the semi-desert, 300 mm to 1,500 mm in the woodland savannas and to over 1,500 mm in the montane vegetation (Fig. 6). The rainfalls ranging from nearly nil in Wadi-Halfa to 167 mm in Khartoum to 1000 mm in Juba. Sudan’s climate is very hot, every part of the country experience maximum average temperatures of over 38°C during several months of the year and many parts experience these temperatures at all times of the year. In the deserts, winter minimum temperatures as low as 5° C are common at night, while summer maximum temperatures often exceed 44° C (Fig. 7). The average temperature in the far North, Wadi-Halfa is about 26^0C (mean maximum 34.6^0C and mean minimum 17.7^0C), Khartoum has a yearly average temperature of about 30^0C (mean max. 37.1^0C and mean min. 22.4^0C) and Juba has 27.5^0C (mean max. 33.9^0C and mean min. 21.1^0C) (MEM, 2000; Bilal, 2002; FAO, 2003; MEPD/HCENR, 2003).

3.1.3 Demography

In 2004, the United Nations Population Division estimated Sudan's population at 36.2 million and during the period of 2000-2004, the annual growth rate was 1.93 %. During the same period the number of births per 1,000 population was 33; the number of deaths, 11. The infant mortality rate per 1,000 live births was estimated at 72. Life expectancy at

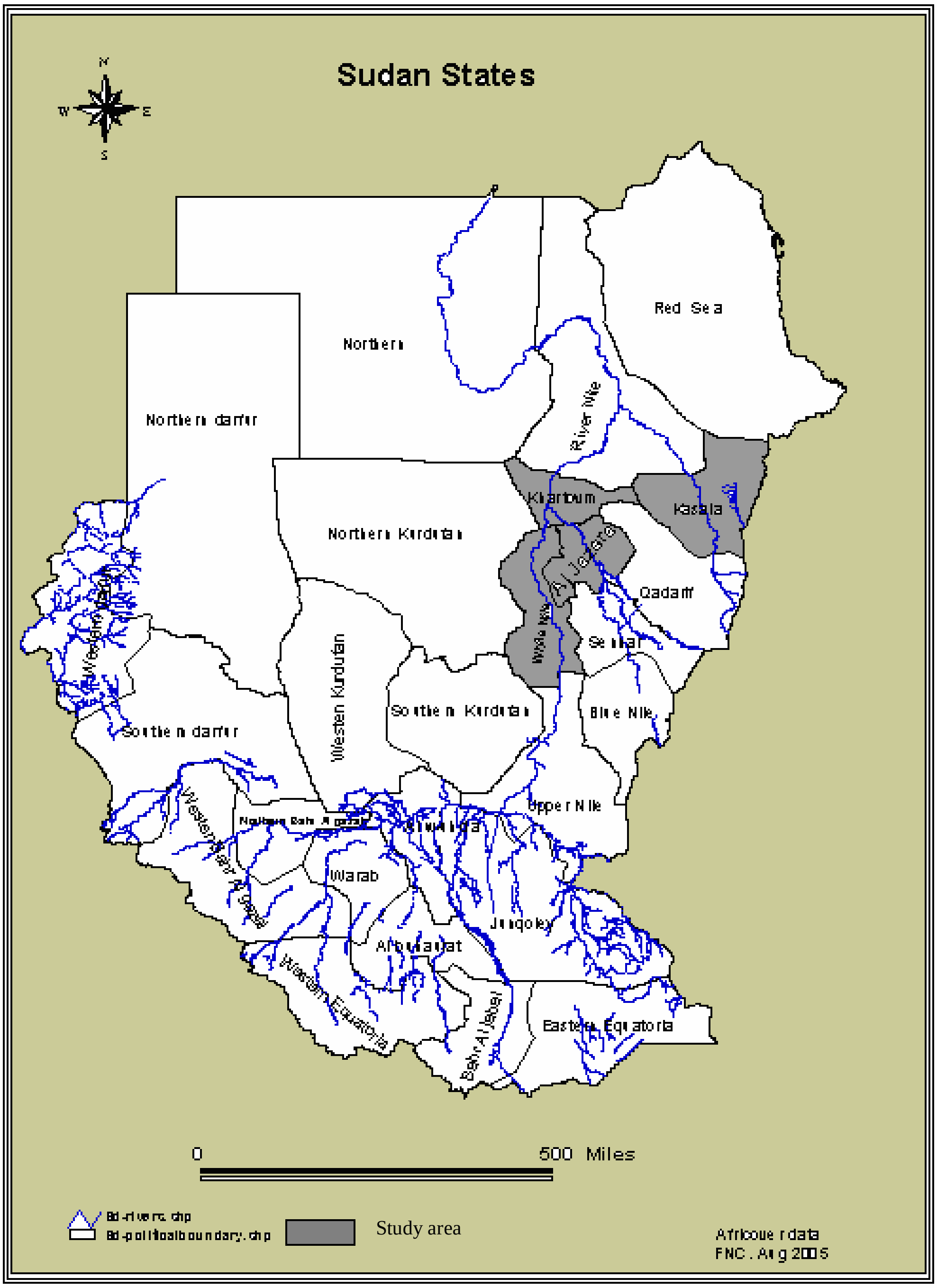

Figure 5. Location of the study area (adapted and modified from FNC)[22]

[22] Outline map of the study area obtained from the office of Forests National Corporation (FNC), Sudan.

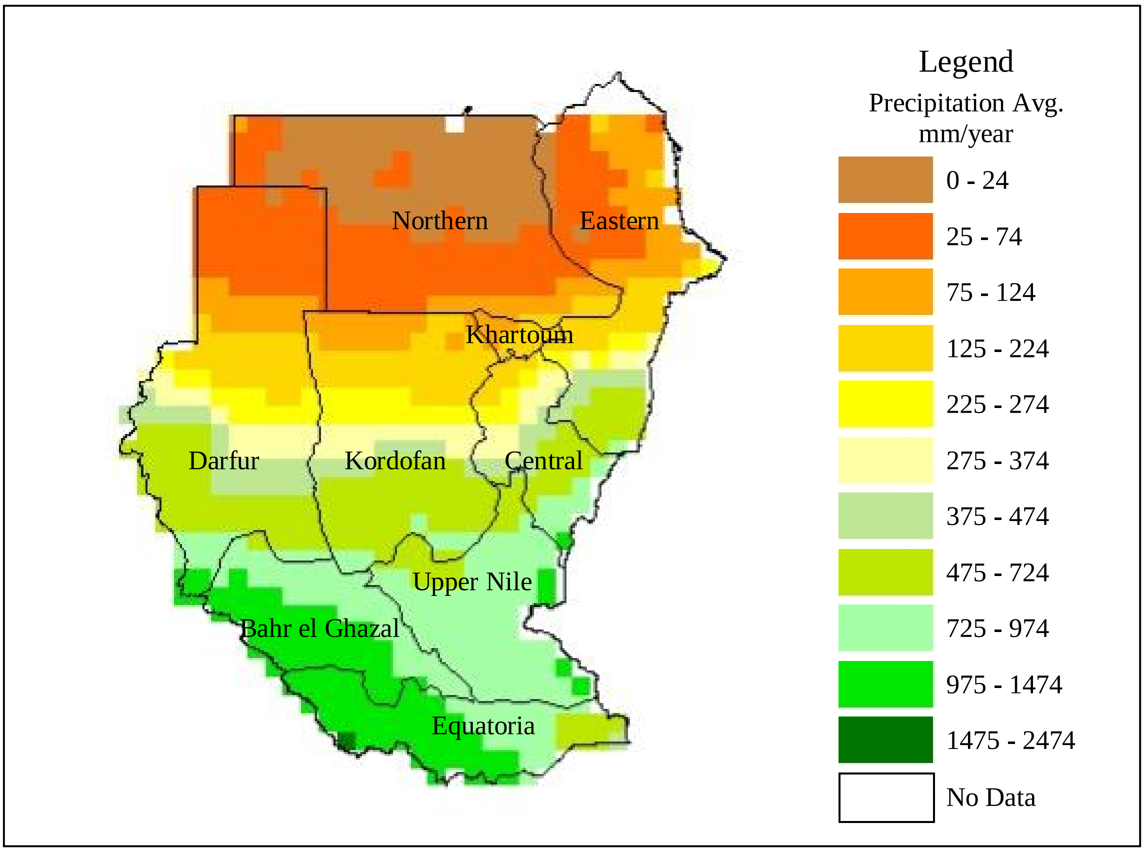

Figure 6. Annual average precipitation of Sudan in mm (Adapted from FAO, 2005b)

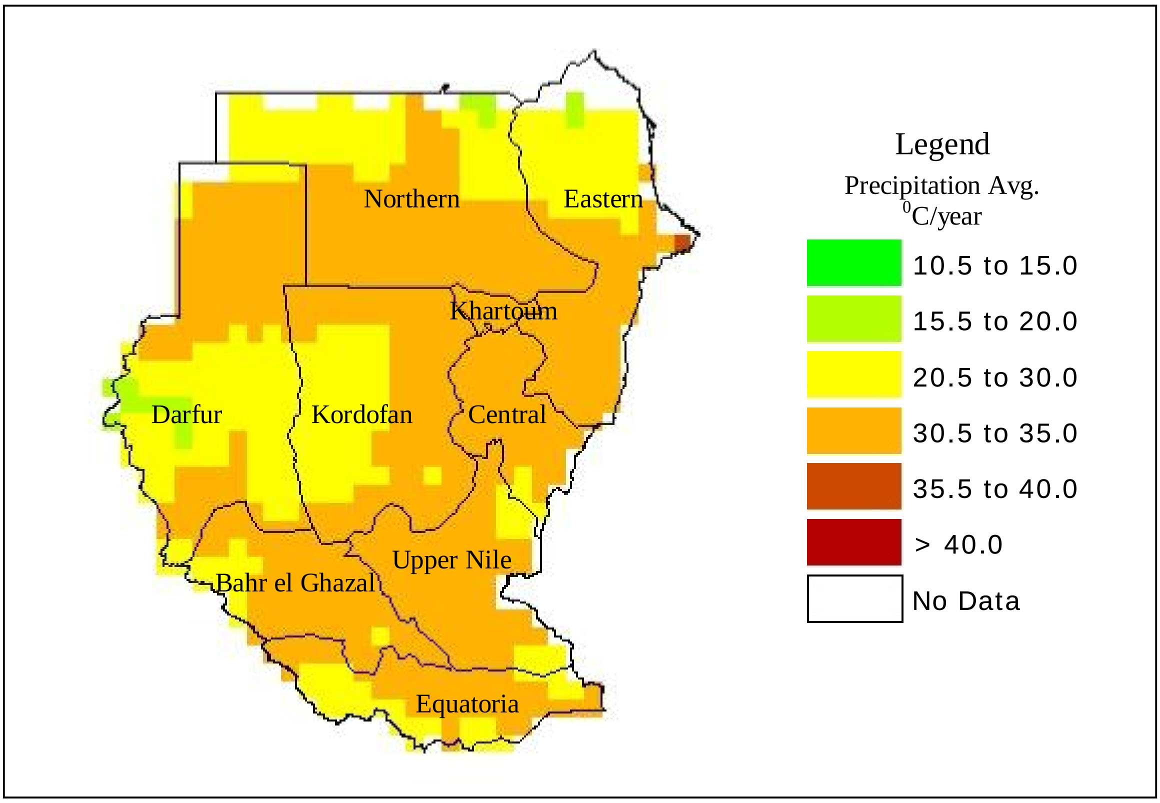

Figure 7. Annual average temperature of Sudan in ^{0}C (Adapted from FAO, 2005b)

birth was an estimated average of 56 years. In 2004, 44 % of the population was less than 15 years of age; 54 % was between the ages of 15 and 64 years, and those aged 65 years and older accounted for slightly more than 3 %. In the overall population, there were 1.01 males for every female. The United Nations also estimated the population density in 2004 at 14 persons per square kilometre which seems to a misleading measurement because half of the population lives on approximately 15 % of the land, and the northern part of the country is quite thinly populated. Estimates of urbanization ranged from 31 % to 37 %, with the greatest concentration in the greater Khartoum area (LCFRD, 2005; UN, 2005).

3.1.4 Land use pattern

Sudan's landscape composed of vast plains interrupted by a few widely separated ranges of hills and mountains. The most important ranges are Jebel Mara in the West, the Amatong in the extreme south-eastern part of the country and Red Sea Hills. Sudan encompasses an area of about 250 million ha. Of which arable land (84 mill. ha) constitutes about one third of the total area of the country but only 21% (17 mill. ha) of this arable land is actually cultivated. Over 45% (115 mill. ha) of the total area of Sudan consists of permanent pasture and 25% (65 mill. ha) of forests and wood land (MEM, 2000; MEPD/HCENR, 2003).

3.1.5 Vegetation

According to the environmental climatic conditions, the vegetation in the Sudan considerably varies from total desert in the North to tropical rainforests in the south. From the Southern part of the country to about latitude 5^0C and 10^0C N there are high wood lands Savannah which gradually change into low wood lands Savannah stretching approximately to the 14^{th} parallel and up to Gedarif region. This is followed by semi-desert and short grasslands including the Southern part of the Red Sea Hills, which extends to about 15^0C N where the desert area begins. Generally the vegetation can be divided into seven principal types which in general follow the isohyets and form consecutive series from North to South namely, i) Desert ii) Acacia desert scrub iii) Acacia short grass scrub iv) Acacia tall grass scrub v) Broad-leaved woodland and forests vi) Forests vii) Swamps and grasslands (Abdel Nour, 1999; Bilal, 2002).

3.1.6 Infrastructural development

Buildings in Sudan can be classified into three groups: i) buildings made of clay and unbaked brick; ii) those made of red brick, and iii) those made of reinforced concrete cement. Structures made from clay or unbaked bricks also, methods came from the Turkish era, include other construction materials such as bamboo. These comprise about 35% of buildings in Sudan. Buildings made of red brick comprise most government buildings, and 50% of all construction which have stylistic influence of both the Egyptians and British. During the last two decades reinforced concrete construction has greatly increased as a result of expatriate influences, development and exchange of information. These buildings comprise 15% of all construction (MEPD/HCENR, 2003). The second type of construction made of red bricks mainly depends on Sudanese traditional fired clay brick kiln.

3.1.7 Energy use

Biomass is the primary source of energy in the Sudan and in 1995 its contributed 78.5% of Sudan’s total energy supply. In that year, 70.5% was in the form of woody fuel and only 8% was non-woody biomass. The other primary energy source is petroleum products, which contribute 19.4% of total energy supply. Hydro electricity contributes a tiny share of total energy supply, at just 2.1%. In 1995, net energy consumption in the Sudan was about 6.3 million TOE. During that year, total petroleum consumption was 1.35 million TOE. Of this, about 0.63 million TOE (46.25%) of the total was used in transportation, 0.3 million TOE (21.8%) in the electric sector, 0.17 million TOE (12.4%) in manufacturing, 0.17 million TOE (13%) in agriculture, 0.05 million TOE (3.9%) in depots, 12,775 TOE (1%) in construction, 2,980 TOE (0.22%) in mining, and 0.02 million TOE (1.6%) was consumed by households (MEPD/HCENR, 2003). In 1997, consumption of total biomass in the energy sector of Northern Sudan reached about 14 million m^3 consisting of 7.5 million m^3 of fuel wood and 6 million m^3 of charcoal (Tab. 12).

Table 12. Biomass consumption by sector in the Northern Sudan

Sector	Fuelwood (m^3)	Charcoal (m^3)	Total (m^3)	%
Residential	6,148,380	6,070,207	12,218.587	88.5
Industrial	1,050,174	11,673	1,061,847	7.6
Commercial	31,636	283,899	315,535	2.3
Khalwa[23]	209,044	-	209,044	1.6
Total	7,439,234	6,365,779	13,805,013	100

(Adapted from MEPD/HCENR, 2003)

3.2 Sampling method

The present study was accomplished with the observation of 25 randomly selected brick making industries from three administrative regions of Sudan namely, Khartoum, Kassala and Gezira. Of these, 15 were in Khartoum state, which has the major share of total brick making industries in the Sudan (about 2,000 out of the total of 3,450 brick plants in the country). From both of the other two states, five representative brick making industries were surveyed. The total number of brick making industries in Gezira and Kassala is about 800 and 70, respectively.

3.3 Data collection

Data or information about type of enterprise, working staff's, sources and type of raw materials, production capacity, total quantity of fuelwood, dung cake (*Gercaf*) etc used for brick burning, marketing channels, general income for year, socio-economic information and problems related to these etc were collected through either personal contact of entrepreneurs or interviewing from different level of staff's of the respective enterprises. In addition to that, discussion and interview sessions were conducted to different key persons and experts such as Secretary of brick making owners association, Khartoum State, scientists and experts from HCENR, FNC, and BRRI, teachers from Faculty of Forestry, University of Khartoum etc. Different libraries were surveyed for reviewing literature namely, FNC, BRRI, HCENR, IES (Institute of Environmental Studies) and Faculty of Forestry, University of Khartoum. Moreover, data were also collected from three administrative States of Sudan namely White Nile, Kassala and Gezira to explore future potential of fuelwood plantation in the Sudan. For this, respective resource persons[24] were interviewed after visiting plantation sites.

[23] Islamic school where the Holy Quran has been taught
[24] Rahma A. Rahman Ahmed, Forestry Manager. Kenana Sugar Company, White Nile State, Sudan;

3.4 Data processing

3.4.1 Estimation of deforestation

The potential deforestation is typically measured in units of cubic meter (m^3) and is often provided for the commercial portion of biomass only (i.e., round wood). In this case, the data of mass units (t dm) needs to be converted into cubic meter (m^3) and could be measured as deforestation, m^3 per unit of time (WB, 1998).

Conversion to cubic meters is accomplished by dividing the mass units by the density of wood, using the default density value 0.65 t dm/m^3 (Dixon *et al*., 1991). To account for the non-commercial biomass (e.g. branches), an expansion ratio (1.90) should also be applied (Brown *et al*., 1989, and ECE/FAO, 1992 as cited in UNEP/OECD/IEA/IPCC, 1997). Finally, the total volume of wood deforested could be enumerated.

3.4.2 Estimation of greenhouse gas emission from biomass fuel (fuelwood and dung cake) burning in the brick making industries of Sudan

The methodological approach was adopted and modified from the procedures outlined by the Intergovernmental Panel on Climate Change (IPCC) to estimate the rate of greenhouse gas emission caused by brick making industries in the Sudan (IPCC, 1994; WB, 1998).

Estimation of CO_2 emission from fuelwood and dung cake burning

Estimation of carbon content in biomass

The quantity of biomass (t dm) needs to be converted to units of Carbon (C) to estimate CO_2 impacts. This is accomplished by multiplying by the carbon content of biomass, which is measured in units of tonnes of carbon per tonne of dry matter (t C/t dm). To accomplish this, a default value of 0.5 t C/t dm should be used for woody biomass and 0.45 t C/t dm should be applied for non woody biomass.

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Estimation of the total carbon released

To estimate the carbon released, the quantity of biomass burnt (t dm) is multiplied by the fraction of biomass oxidized and the biomass carbon content (t C/t dm). The default value for the fraction of biomass oxidized is 0.9. To convert t C to t CO_2, the ratio of 44 t CO_2/12 t C should be applied.

Total carbon released (t C) = Total biomass burnt (t dm) $\times$ Fraction of biomass oxidized (0.9) $\times$ Biomass carbon content (for woody biomass, 0.5 t C/t dm and non-woody biomass 0.45 t C/ t dm)

Estimation of CO_2 emission from the fuelwood burning

Total fuelwood burnt (t dm) $\times$ Fraction of biomass oxidized (0.9) $\times$ Biomass carbon content (0.5 t C/t dm) $\times$ 44/12 = Total CO_2 (t CO_2) released from the fuelwood burning.

Estimation of CO_2 emission from dung cake burning

Total dung cake burnt (t dm) $\times$ Fraction of biomass Oxidized (0.9) $\times$ Biomass carbon content (0.45 t C/t dm) $\times$ 44/12 = Total CO_2 (t CO_2) released from the dung cake burning.

Estimation of non-CO_2 trace gases emission from biomass fuel (fuelwood and dung cake) burning in the brick making industries of Sudan (Delmas, 1993; Lacaux, 1993; Crutzen and Andreae, 1990; WB, 1998).

CH_4 emissions (t CH_4) = Carbon released (t C) $\times$ Emission ratio (0.012) $\times$ 16/12.

CO emissions (t CO) = Carbon released (t C) $\times$ Emission ratio (0.060) $\times$ 28/12.

N_2O emissions (t N_2O) = Carbon released (t C) $\times$ Emission ratio (0.007) $\times$ N/C ratio (0.01) $\times$ 44/28.

NOx emissions (t NOx) = Carbon released (t C) $\times$ Emission ratio (0.121) $\times$ N/C ratio (0.01) $\times$ 46/14.

NO emissions (t NO) = Carbon released (t C) $\times$ Emission ratio (0.121) $\times$ N/C ratio (0.01) $\times$ 30/14.

4 RESULTS

4.1 Potential deforestation caused by the brick making industries in the study areas of Sudan

The study revealed that the total annual quantity of fuelwood consumed by the surveyed brick making industries (25) was 2,381 t dm with an average of 95 t dm per BMI per annum. As a result, the observed total potential deforested wood was 10,624 m^3 (SD 484), in which the total deforested round wood was 3,664 m^3 (SD 167) and deforested branches was 6,961 m^3 (SD 317) (Tab. 13). For brick burning, 13 tree species were reported to be used as fuelwood: Sunt (*Acacia nilotica*), Talh (*Acacia seyal*), Kitir (*Acacia mellifera*), Seyal (*Acacaia tortilis*), Laot (*Acacia nubica*), Haraz (*Faidherbia albida*), Neem (*Azadirachta indica*), Eucalyptus (*Eucalyptus* spp.), Mesquite (*Prosopis juliflora*), Tundub (*Capparis decidua*), Mango (*Mangfiera indica*), Grape fruit (*Citrus paradisi*) and Guava (*Psidium guajava*). Of these, fruit species and mesquite are commonly used in Kassala state while the other species are most popular in the brick making industries in Khartoum state. Sunt is most commonly used species in Gezira State though other species were also used insignificantly.

4.2 Emission of greenhouse gases from the brick making industries in the study areas of Sudan due to the consumption of fuelwood

The study observed that all the surveyed BMIs (25) consumed a total of 2,381 t dm (SD 108) annually with an average of 95 t dm. Due to the burning of that quantity of fuelwood 3,929 t CO_2 (SD 179), 17 t CH_4 (SD 0.78), 150 t CO (SD 7), 0.12 t N_2O (SD 0.005), 4 t NO_X (SD 0.19) and 3 t NO (SD 0.13) were estimated to emit in the atmosphere per year by the surveyed BMIs in the study areas of Sudan. On the basis of average annual rate of emission per BMI, the study was also observed that the highest emitted greenhouse gas was CO_2 (157 t) followed by CO (6 t), CH_4 (0.7 t), NO_X (0.17 t), NO (0.11 t) and N_2O (0.005 t) respectively (Tab. 14).

Table 13. Potential annual deforestation caused by the brick making industries (25 units), in the study areas of Sudan due to the consumption of fuelwood

Name of the enterprises*		Total brick production /year (in "000")	Fuelwood consumption in kg /1000 bricks	Fuelwood consumption /year (t dm)	Deforested round wood (m^3)	Deforested Branches (m^3)	Total deforested wood (m^3)
Khartoum State	SK1	1120	50.67[A]	56.75	87.31	165.89	253.19
	SK2	1500	50.67	76.01	116.93	222.17	339.10
	SK3	1000	50.67	50.67	77.95	148.11	226.07
	SK4	1035	50.67	52.44	80.68	153.30	233.98
	SK5	1000	50.67	50.67	77.95	148.11	226.07
	EK1	1500	50.67	76.01	116.93	222.17	339.10
	EK2	1200	50.67	60.80	93.54	177.73	271.28
	EK3	720	50.67	36.48	56.13	106.64	162.77
	EK4	1135	50.67	57.51	88.48	168.11	256.59
	EK5	900	50.67	45.60	70.16	133.30	203.46
	KK1	800	50.67	40.54	62.36	118.49	180.85
	KK2	500	50.67	25.34	38.98	74.06	113.03
	KK3	600	50.67	30.40	46.77	88.87	135.64
	HK1	800	50.67	40.54	62.36	118.49	180.85
	HK2	1000	50.67	50.67	77.95	148.11	226.07
Kassala State	K1	450	533[B]	239.85	369.00	701.10	1070.10
	K2	660	533	351.78	541.20	1028.28	1569.48
	K3	480	533	255.84	393.60	747.84	1141.44
	K4	500	533	266.50	410.00	779.00	1189.00
	K5	720	533	383.76	590.40	1121.76	1712.16
Gezira State	HG1	360	39[C]	14.04	21.60	41.04	62.64
	HG2	880	39	34.32	52.80	100.32	153.12
	HG3	750	39	29.25	45.00	85.50	130.50
	HG4	750	39	29.25	45.00	85.50	130.50
	HG5	675	39	26.33	40.50	76.95	117.45
Total		21,035	3,620.05	2,381.34	3,663.60	6,960.83	10,624.43
Average		841.4	144.802	95.25	146.54	278.43	424.98
SD		302.42	198.16	108.49	166.90	317.12	484.02

*SK= Shambat, Khartoum; EK=Elgeref, Khartoum; KK= Koko, Bahri, Khartoum; HK= Halfia, Bahri, Khartoum; K= Kassala and HG= Hasahisa, Gezira.

[A, B, C] Data obtained from (Hamid, 1994)

Table 14. Annual emission of greenhouse gases by the brick making industries (25 units), in the study areas of Sudan due to the consumption of fuelwood for brick burning

Name of the enterprises*		Fuelwood consumption /year (t dm)	Carbon Released (t C)	CO_2 (t)	CH_4 (t)	CO (t)	N_2O (t)	NO_X (t)	NO (t)
Khartoum State	SK1	56.75	25.54	93.64	0.41	3.58	0.003	0.102	0.066
	SK2	76.01	34.20	125.41	0.55	4.79	0.004	0.136	0.089
	SK3	50.67	22.80	83.61	0.36	3.19	0.003	0.091	0.059
	SK4	52.44	23.60	86.53	0.38	3.30	0.003	0.094	0.061
	SK5	50.67	22.80	83.61	0.36	3.19	0.003	0.091	0.059
	EK1	76.01	34.20	125.41	0.55	4.79	0.004	0.136	0.089
	EK2	60.80	27.36	100.33	0.44	3.83	0.003	0.109	0.071
	EK3	36.48	16.42	60.20	0.26	2.30	0.002	0.065	0.043
	EK4	57.51	25.88	94.89	0.41	3.62	0.003	0.103	0.067
	EK5	45.60	20.52	75.24	0.33	2.87	0.002	0.082	0.053
	KK1	40.54	18.24	66.88	0.29	2.55	0.002	0.073	0.047
	KK2	25.34	11.40	41.80	0.18	1.60	0.001	0.045	0.030
	KK3	30.40	13.68	50.16	0.22	1.92	0.002	0.054	0.035
	HK1	40.54	18.24	66.88	0.29	2.55	0.002	0.073	0.047
	HK2	50.67	22.80	83.61	0.36	3.19	0.003	0.091	0.059
Kassala State	K1	239.85	107.93	395.75	1.73	15.11	0.012	0.429	0.280
	K2	351.78	158.30	580.44	2.53	22.16	0.017	0.629	0.410
	K3	255.84	115.13	422.14	1.84	16.12	0.013	0.458	0.299
	K4	266.50	119.93	439.73	1.92	16.79	0.013	0.477	0.311
	K5	383.76	172.69	633.20	2.76	24.18	0.019	0.687	0.448
Gezira State	HG1	14.04	6.32	23.17	0.10	0.88	0.001	0.025	0.016
	HG2	34.32	15.44	56.63	0.25	2.16	0.002	0.061	0.040
	HG3	29.25	13.16	48.26	0.21	1.84	0.001	0.052	0.034
	HG4	29.25	13.16	48.26	0.21	1.84	0.001	0.052	0.034
	HG5	26.33	11.85	43.44	0.19	1.66	0.001	0.047	0.031
Total from 25 BMI		2,381.34	1,071.60	3,929.21	17.15	150.02	0.12	4.26	2.78
Average		95.25	42.86	157.17	0.69	6.00	0.0047	0.17	0.11
SD		108.49	48.82	179.00	0.78	6.83	0.0054	0.19	0.13

*SK= Shambat, Khartoum; EK=Elgeref, Khartoum; KK= Koko, Bahri, Khartoum; HK= Halfia, Bahri, Khartoum; K= Kassala and HG= Hasahisa, Gezira.

4.3 Emission of greenhouse gases from the brick making industries of Khartoum State in the Sudan due to the consumption of dung cake

The study revealed that dung cake is only used in the brick burning industries of Khartoum state and it was estimated that total 608 t dung cake with an average of 41 t (SD 9) was consumed by 15 BMIs of Khartoum State. Due to the burning of that quantity of dung cake 903 t CO_2 (SD 13.45), 4 t CH_4 (0.06), 34 t CO (SD 0.5), 0.03 t N_2O (SD 0.0004), 1 t NO_X (SD 0.01) and 0.64 t NO (SD 0.01) were estimated to emit in the atmosphere per year by the surveyed BMIs (15 units) in the study areas of Khartoum, Sudan while the annual total carbon released in the atmosphere was 246 t. On the basis of average annual rate of emission per BMI, the study was also observed that the highest emitted greenhouse gas was CO_2 (60 t) followed by CO (2.3 t), CH_4 (0.26 t), NO_X (0.07 t), NO (0.04 t) and N_2O (0.002 t) respectively (Tab. 15).

4.4 Emission of greenhouse gases from the surveyed brick making industries in the Sudan due to the consumption of biomass fuels

The study observed that a total of 2,990 t biomass fuel (fuelwood and dung cake) consumed by the surveyed BMIs (25 units) annually for brick burning. By considering all categories of biomass fuels (fuelwood and dung cake) it was estimated that the total annual emissions of greenhouse gases were 4,832 t CO_2, 21 t CH_4, 184 t CO, 0.15 t N_20, 5 t NO_X and 3.5 t NO while the total carbon released in the atmosphere was 1,318 t. Altogether, the total annual greenhouse gas emission from biomass fuel burning was 5,046 t; of which 4,104 t from fuelwood and 943 t from dung cake burning (Tab.16). It is also observed that emission from dung cake is considerably low as it is only used in the BMIs of Khartoum State and dung cake consumption for brick burning is also relatively small in quantity.

4.5 Prediction of maximum potential deforestation caused by the brick making industries in the Sudan

The Brick Making Owners' Association in Khartoum State provided information[2] that there are about 3,450 brick making industries in the Sudan. Based on the average fuelwood consumption in the brick making industries of Sudan, the study estimated that the total amount of harvested wood for 3,450 brick making industries contributing to deforestation annually would be 1,467,000 m^3, of which amount stem round wood and branch wood would amount to 506,000 m^3 and 961,000 m^3 respectively (Tab.17).

Table 15. Annual emission of greenhouse gases by the brick making industries (15 units) of Khartoum in the Sudan due to the consumption of dung cake for brick burning

Name of the enterprises*		Dung cake consumption /year (t)	Carbon Released (t C)	CO_2 (t)	CH4 (t)	CO (t)	N_2O (t)	NOx (t)	NO (t)
Khartoum State	SK1	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
	SK2	60	24.30	89.10	0.39	3.40	0.002673	0.10	0.06
	SK3	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
	SK4	36	14.58	53.46	0.23	2.04	0.001604	0.06	0.04
	SK5	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
	EK1	60	24.30	89.10	0.39	3.40	0.002673	0.10	0.06
	EK2	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
	EK3	32	12.96	47.52	0.21	1.81	0.001426	0.05	0.03
	EK4	48	19.44	71.28	0.31	2.72	0.002138	0.08	0.05
	EK5	36	14.58	53.46	0.23	2.04	0.001604	0.06	0.04
	KK1	32	12.96	47.52	0.21	1.81	0.001426	0.05	0.03
	KK2	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
	KK3	32	12.96	47.52	0.21	1.81	0.001426	0.05	0.03
	HK1	32	12.96	47.52	0.21	1.81	0.001426	0.05	0.03
	HK2	40	16.20	59.40	0.26	2.27	0.001782	0.06	0.04
Total from 15 BMI		608	246.24	902.88	3.94	34.47	0.0271	0.98	0.64
Average		40.53	16.42	60.19	0.26	2.30	0.0018	0.07	0.04
SD		9.05	3.67	13.45	0.06	0.51	0.0004	0.01	0.01

*SK= Shambat, Khartoum; EK=Elgeref, Khartoum; KK= Koko, Bahri, Khartoum; HK= Halfia, Bahri, Khartoum.

Table 16. Annual emission of greenhouse gases from the surveyed brick making industries (25 units) by considering all categories of biomass fuels (fuelwood and dung cake)

Categories of fuel	Mean and total observation	Biomass fuel consumed per annum (t)	Carbon released (t C)	CO_2 (t)	CH_4 (t)	CO (t)	N_2O (t)	NO_X (t)	NO (t)	Total (t)
Fuelwood (consumed by BMIs of all the 3 states of study areas in Sudan)	Mean observation (from 25 BMIs of Khartoum, Kassala & Gezira States)	95.25	42.86	157.17	0.69	6.00	0.0047	0.17	0.11	-
	Total from 25 BMIs of the study areas	2,381.34	1,071.60	3,929.21	17.15	150.02	0.12	4.26	2.78	4,103.54
Dung Cake (only consume in Khartoum State)	Mean observation (from 15 BMI of Khartoum State)	40.53	16.42	60.19	0.26	2.30	0.0018	0.07	0.04	-
	Total from 15 BMIs of Khartoum State	608	246.24	902.88	3.94	34.47	0.0271	0.98	0.64	942.94
Grand Total	Total emissions from BMIs (considering both categories of biomass fuels)	2,989.34	1,317.84	4,832.09	21.09	184.49	0.1471	5.24	3.42	5,046.48

Table 17.Total annual potential deforestation caused by the brick making industries (3,450 units) in the Sudan due to the consumption of fuelwood for brick burning

Mean and total observation	Annual fuelwood consumption (t dm)	"Deforesting" round wood (m^3)	"Deforesting" branches (m^3)	Total "de-foresting" wood (m^3)
Mean observation (from 25 BMI of Khartoum, Kassala & Gezira States)	95.25	146.54	278.43	424.98
Total from 3,450 BMIs of Sudan	328,624	505,576	960,594	1,466,171

4.6 Prediction of annual greenhouse gas emission from the brick making Industries in the Sudan due to the consumption of biomass fuels

The present study suggests that the annual quantity of fuelwood required for the 3,450 brick making industries in the Sudan would be 328,600 t dry matter. Due to the burning of that quantity fuelwood, 542,200 t CO_2, 2,366 t CH_4, 20,700 t CO, 16 t N_2O, 588 t NO_X and 383 t NO would be emitted per annum, while the total amount of carbon released into the atmosphere would be annually 147,900 t (Tab. 18).

It was also estimated that the annually required quantity of dung cake (here assumed as sustainably used, carbon-neutral fuel) for the approximately 2,000 brick making industries that use this fuel in the Sudan would be 81,100 t (this biomass fuel is only used in Khartoum State). Consequently, 120,400 t CO_2, 525 t CH_4, 4,600 t CO, 4 t N_2O, 130 t NO_X and 85 t NO were estimated to be emitted annually, while the total amount of carbon released from this fuel source into the atmosphere annually would be 32,800 t (Tab. 18).

By considering both two categories of biomass fuels (fuelwood and dung cake) together, the total emissions from the 3,450 brick making industries in the Sudan would be 662,600 t CO_2, 2,900 t CH_4, 25,300 t CO, 20 t N_2O, 720 t NO_X and 470 t NO per annum, while the total amount of carbon thus released would be 180,700 t (Tab. 18).

4.7 Employment in the brick making industries of Sudan

The number of workers in any brick making industry largely depends on the numbers of tables per production unit, number of workers per table and the number of workers required to fire the kiln. The number of tables per production unit used to vary 2-4 and the number of workers per table is 2 (Appendix 2, plate 3). The number of workers for kiln operations (loading, stacking, firing and unloading) ranges between 2 and 6. Moreover, workers are also employed as cleaner (1 person), mechanic for water pump (1 person as temporary basis), guard (1 person) and another one person for administrative purposes. The total number of workers per production unit is about 10 (2×2+2+4) to18 (4×2+6+4). As a result, we may predict that the total number of workers employed in the brick making industries of Sudan is about 34,500 to 62,100, considering the total number of brick making industries in the Sudan is 3,450. As the size of all brick making industries are not same so roughly number of workers employed in the brick making of industries in the Sudan would be 50,000, of this half of workers employed in Khartoum state.

Table 18. Total annual emission of greenhouse gases from the brick making industries (3,450) in the Sudan due to burning of biomass fuels (fuelwood and dung cake)

Categories of fuel	Mean and total observation	Biomass fuel consumption t dm / annum	Carbon released (t C)	CO_2 (t)	CH_4 (t)	CO (t)	N_2O (t)	NO_X (t)	NO (t)
Fuelwood (consumed by BMIs of all the 3 states of study areas in Sudan)	Mean observation (from 25 BMIs of Khartoum, Kassala & Gezira States)	95.25	42.86	157.17	0.69	6.00	0.0047	0.17	0.11
	Total from 3,450 BMI of Sudan	328,624	147,881	542,230	2,366	20,703	16.27	587.93	383.43
Dung Cake (only consumed by BMIs of Khartoum State)	Mean observation (from 15 BMI of Khartoum State)	40.53	16.42	60.19	0.26	2.30	0.0018	0.07	0.04
	Total from 2000 BMI of Khartoum State	81,066	32,832	120,384	525.31	4,596.48	3.61	130.53	85.13
Grand Total	Total emissions from 3,450 BMIs (considering both categories of biomass fuels)	409,690	180,713	662,614	2,891	25,299	19.88	718	468

4.8 Potentials of fuelwood plantation in the Sudan

4.8.1 Irrigated plantation by Kenana Sugar Company Ltd.[24]

Background

The gigantic Kenana Sugar Company (KSC) Ltd. started late seventies of last century. Land preparation to grow sugarcane removed the natural vegetation over the 160,000 feddans[25], which is the gross area of the scheme. The forestry project started 1993/94 to compensate the vegetation removed. Forest plantations are established within the irrigated KSC Ltd. Estate near *Rabak* on the eastern bank of the White Nile, about 270 Km from Khartoum. KSC Ltd. Site falls in the *Jabalian* province of the White Nile state (Latitude 13^0 N, Longitude 33^0 E and altitude of 410 m). The forest sites are scattered in and around Kenana's six areas of sugarcane field. These sites are about 2-30 km from Kenana Township.

Objectives of irrigated plantation:

1. To compensate the natural vegetation, which has been removed to grow sugar cane.
2. To maximize land utility by cultivating lands not suitable for sugar cane.
3. To utilize the drainage water of sugar cane crop.
4. To avail wind break around sugar cane fields to minimize the effect of the desiccating winds.
5. To preserve the microclimate.
6. To serve amenity purposes.
7. To avail fuel wood for domestic use.
8. To avail building poles for local community.
9. To avail grazing area for domestic animals.

Plantation activities and production

A total of 7,000 feddans were planted until 2000/01 started from 1993/94. Of which, 3,400 feddans were planted by *Eucalyptus* sp. (Plate 12), followed by *A. senegal* (1,700 feddans), *A. nilotica* (1,450 feddans; Plate 13), *A. seyal* (550 feddans) and others (70 feddans) respectively (Tab. 19). Among all the species, *A. nilotica* was planted for fuelwood production. Other uses of the plantation project were building poles (*Eucalyptus*

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[25] 1 feddan = 0.42 ha or 4,200 m^2; 1 hectare = 2.38 feddans

sp.), charcoal (*A. seyal*) and gum production (*A. senegal*). The study also found out during the period of 1999/2000 to 2003/04 from *Eucalyptus camaldulensis* species about 3,400 m^3 of fuelwood and 970,000 no. of poles collected and for these, about 207,000 no. of trees were harvested during the same period (Tab.20).

Table 19. Plantation areas (in feddan) and tree species over years

Tree Species	Specific Use	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	Total
Eucalypts sp.	Building poles & fuelwood	475	470	646	500	225	317	588	211	3432
A. nilotica	Fuelwood	400	230	420	300	-	-	84	08	1442
A. seyal	Charcoal	150	100	150	150	-	-	15	-	565
A senegal	Gum production	90	330	300	300	-	185	479	-	1684
Others	--	20	-	16	08	-	10	15	-	69
Total		1,135	1,130	1,532	1,258	225	512	1,181	219	7,192

Table 20. Production of Building Poles and fuelwood from *Eucalyptus camaldulensis* over years

Production year	Area harvested in feddans	No of trees Harvested	No of poles	Fuelwood (m^3)
1999/2000	116	46,765	80,846	247
2000/01	90	48,765	82,169	132
2001/02	438	-	183,195	889
2002/03	498.5	70,749	296,096	741
2003/04	296	41,503	327,562	1,350
Total	1,438.5	207,782	969,868	3,359

First year of fuelwood production from *A. nilotica* started from 2004/05. The number of trees harvested and fuel wood production during this year were 8,853 and 2,415 m^3 respectively. During the same year charcoal and fuel wood production, for the first time, from *A. seyal* were 150 sac (1 sac = 50 kg) and 483 m^3 respectively. Generally, for the production of 3 sacs charcoal 1 m^3 wood is required and 10 years old five *A. seyal* trees can provide 1 m^3 wood. In 1998, after four years of *A. senegal* plantation, the first tapping was done in about 21,000 trees for gum production but the production was only 20 kg. As a result KSC administration organized a workshop in 2001 (July 22-25) to identify the probable solutions of the low production of gum from *A. senegal*. All probable causes were patiently examined during the workshop but no definite answer to the problem could be reached. Eventually, KSC administration decided to replace *A. senegal* plantation by *A. nilotica* in near future.

Plate 12. Irrigated Eucalyptus plantation by KSC at White Nile State

Plate 13: Irrigated Sunt (*A. nilotica*) plantation by KSC at White Nile State

Constraints facing for future development

- KSC project depends on marginal lands that are either high lands or away from the water sources, so highly expensive power water pumps are required or big size lakes to be constructed to serve as reservoirs with control gates.
- Irrigated water sometime is not sufficient for cane crop requirements mainly during hot summer months (May-June) resulting in long dry periods on forestry plantations.

Bases on the above the company expects local and international assistance in training and technology sphere.

Expected future activities

- Expansion in the plantations to reach 20,000 feddans.
- Establishment of small scale industries like fibre board and particle board.
- Establishment of seed orchards for genetic improvement and conservation.

Observation

The project was reasonably successful in achieving some of the set goals. Beside the environmental benefits the followings were achieved.

- Establishment of more than 7,000 feddans of forest tree species
- Establishment of community plots.
- Production of wood poles and other woody materials for the local markets.
- Provision of grazing lands for domestic animals (under the trees).
- Use of all the marginal land within Kenana estate.
- Efficient use of the drainage water from the sugar cane fields.

4.8.2 Irrigated plantation by Forests National Corporation (FNC) at Kassala State[24]

Background

Kassala state is located between longitude $35^0 55^/$ and $37^0 55^/$ E, latitude $14^0 15^/$ and $17^0 15^/$ N and about 600 Km away from Khartoum. The area of the state is 4,282 km^2. The state is divided into four circles for administrative purposes. The capital of the state is Kassala. Rainfall is between 100-400 mm per annum. Dominant species are: *A. mellifera*, *A. seyal*, *Prosopis chilensis* (dominant in northern part). Area of reserved forest of this state is 220,059 feddans, which is 2.2% of the total land area and the total area of plantation forest is 5,082 feddans. Irrigated plantation with agro forestry system has been established at Kassala circle in 1992 under the management of Kassala FNC.

Area of Irrigated Plantation

Until 2004, the size of the total irrigated plantation was 172 feddans. Of which, 50 feddans on the Eastern bank and 42 feddans on the Northern bank of the river Gash and 80 feddans in New Halfa. The proposed area of irrigated plantation in 2005 is 270 feddans (100 feddans in New Halfa, 90 feddans on the Eastern bank and 80 feddans on the Western bank of the river Gash).

Objectives of Irrigated Plantation

- To meet the local demand for building poles and firewood etc.
- To protect the soil erosion along the banks of river Gash.
- To preserve microclimate and to minimize desert creeping and desertification.
- Avail landless farmers to grow/produce agricultural crops as agro forestry (Taungya) system.

Management system and production

For sustainable management of irrigated plantation (Plate 14), initially FNC staff selects the landless farmers of nearby locality of the plantation site and during the selection process, preference used to be given who are well known to Taungya system. 5-10 feddans of land area are allocated per family under the bilateral agreement between FNC and selected local farmers. Farmers have to prepare the land both for forest and agricultural crops and they are also responsible for rearing the plants. FNC only provides seedlings of forest crops and most of the cases seedlings are planted by FNC staff. Extension services are also provided by FNC staff. Farmers used to get benefits from agri-crops as well as from fuelwood collection in case of instant demand. Prescribed tree species for Taungya system were *Eucalyptus camaldulensis* and *E. microthica* while common agri-crops were onion, okra tomato, and green chilli. Spacing of tree crops: 2m (within the lines) × 3m (between the lines).

Plate 14. Small scale pump irrigated Eucalyptus plantation by FNC at Kassala State

In 2004, 67.5 feddans of Eucalyptus plantation were harvested and number of harvested poles was 30,697. There was no fuelwood production after harvesting of first crop and fuel wood production is only possible after second and third crop due to the result of coppicing and sprouting.

Constraints for irrigated plantation

- Lack of funding
- Lack of seedlings and or nursery for plantation
- Lack of vehicle to follow up/monitor of forest plantation and transport of forest produce.

Expected future activities:

- Expansion in the plantation to reach up to 500 feddans
- Expansion of the production of seedlings from the nursery by establishing new nursery.

4.8.3 Sunt (*A. nilotica*) reserve forest managed by FNC at Talbab, El Hassahisa, Gezira State[24]

Background

Talbab Sunt (*A. nilotica*) reserve forest (latitude $14^0 53^/$ N and longitude $33^0 13^/$ E) is located at Western bank of Blue Nile near Talbab village and about 15 Km away from El Hassahisa Town of Gezira State. Talbab sunt forest was declared as reserve forest in 1939. The area of this reserve forest is 375 feddan, of which 306 feddan is the main reserve and the rest 69 feddan is considered as an extension.

Objectives of this reserve forest

1. Fuelwood production especially for the brick making industries
2. Provide grazing facility for the animals of nearby locality

Management system and production

Talbab Sunt reserve forest (Plate 15) is divided into 3 compartments and followed by clear felling with artificial regeneration by seed. The rotation is 20 yrs for the production of fuelwood. After flooding season seeds are spread on the basin of Blue Nile. During normal flooding season untreated seeds are used but in case of low flooding, treated (by H_2SO_4) seeds are used. Pit method is followed for seed sowing and depending on the seed quality and germination capacity of seeds usually 2-4 seeds are sown on each pit. During the rotation period, first thinning is carried out between 4 to 6 years of old plantation, maintaining 2m×2 m spacing, the second one is on 6 to 10 yrs (3m×3m spacing) and the final is on 10 to 15 yrs (4m×4m spacing). The final harvesting usually carried out between 15 to 20 yrs old plantation.

In 2004, a total of 1,800 m^3 fuelwood produced, of which 259 m^3 of fuelwood harvested from second thinning operation of first compartment and the rest 1,541 m^3 came from second compartment after final harvesting. Compartment number three is planned to be harvested in 2006 (Tab. 21).

Table 21. Silvicultural operation and production

Compartment number	Date of plantation	Observation Thinning/harvesting	Area thinned / harvested (in feddan)	Fuelwood Production (m^3)
1	1989	Second thinning (2004)	75	259
2	1984/85	Final Harvesting (2004)	75	1,541
3	1986	Final harvesting (2006)	--	--

Plate 15. Sustainable Sunt (*A. nilotica*) plantation by FNC at Talbab Reserve Forest, Gezira State.

Management constraints

- Dependency on flood and rainfall
- Illicit felling by the local people
- Lac of forest guard (only one person for three compartment)
- Encroachment of the forest land by the local people
- Illegal grazing during establishment of young plantation

5 DISCUSSION

5.1 Consumption of biomass fuels in the brick making industries of Sudan and their implication for deforestation

Biomass contributed 78.5% of Sudan's total energy supply in 1995 (Fig. 8; MEPD/ HCENR, 2003). Woodfuel provides about 69% of the total energy consumption in traditional industries including brick making, bakeries, oil mills, etc. Type of wood consumed is mainly fuelwood (stem wood), which has a significant impact on forest resources (FAO, 2000).

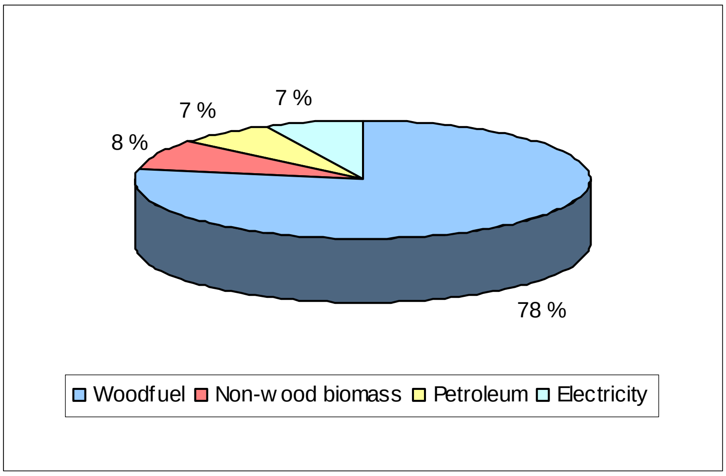

Figure 8. Total energy consumption by type of energy in the Sudan (adapted from FNC, 1995).

FNC (1995) estimated that the industrial sector in 1994 used 1.07 million m^3 round wood, which was 6.8% of the total wood consumption in the Sudan (Fig. 9). Among the traditional industries, brick kilns consumed about 52% of the total wood consumption of the industrial sector (Fig. 10; FAO, 2000). Fired clay bricks are commonly used in most parts of Sudan, and fuelwood is the most commonly used fuel for firing clay bricks, followed by dung cake. Literature study illustrated that there are about 1,700 brick making industries in the Sudan, consuming about 183,000 t of fuelwood, equivalent to 549,000 stacked m^3. The brick production is mainly concentrated in Khartoum and central states which produce 46% and 42% of the total Sudan's production and consume 35% and 27% of the total fuelwood consumption in the brick making sector, respectively. The consumption of wood per 1,000 bricks varies widely from 0.12 to 1.6 m^3 (Hamid, 1994; FNC, 1995).

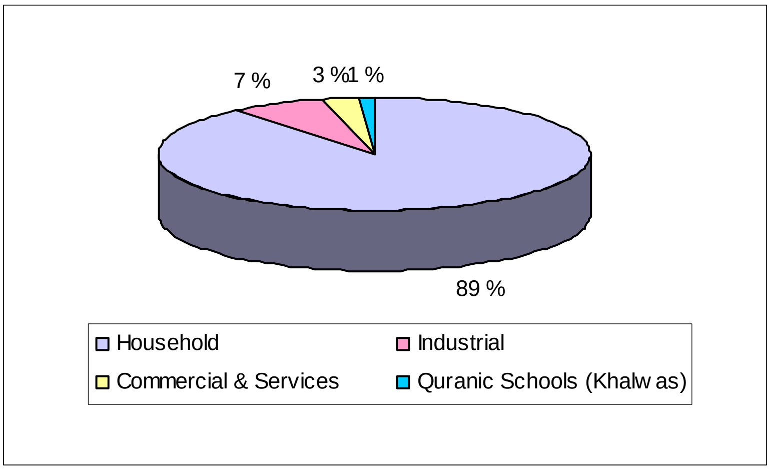

Figure 9: Total wood consumption by sectors (adapted from FNC, 1995).

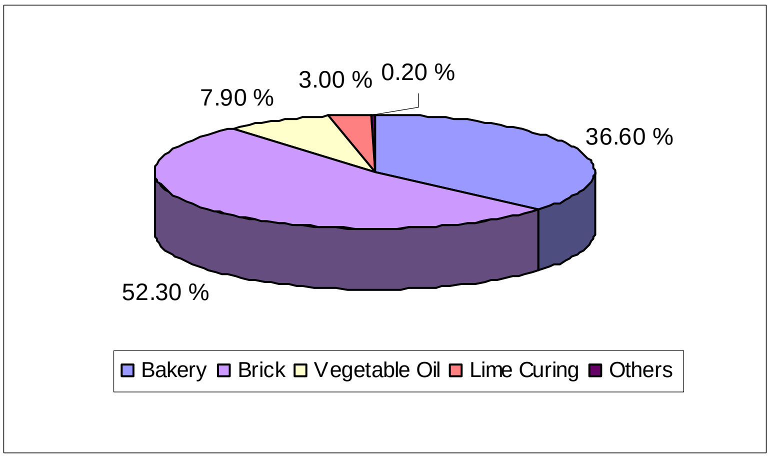

Figure 10: Fuel wood consumption in industrial sector (adapted from FNC, 1995).

The present study revealed that there are about 2,000 brick making industries in Khartoum state and the total number of brick making industries in the Sudan is approximately 3,450. Based on the consumption of fuelwood, the study estimated that the total amount of annual harvested wood, typically considered as potential deforestation, by the all brick making industries of Sudan (3,450 units) would be 1,467,000 m^3, of which 506,000 m^3 is round wood and the rest 961,000 m^3 is branch wood (Tab. 17).

The study also found that dung cake (*Gercaf*) is also used as fuel for brick burning only in Khartoum state, and the annual consumption of dung cake per industry varies widely, ranging between 32 and 60 t (with an average 40.5 t) depending on the size of the plant, annual production and availability of dung cake for brick burning. The total amount of annually consumed dung cake by the brick making industries of Khartoum (2,000 units) would be 81,000 t (Tab. 15).

5.2 Brick making industries in the Sudan-means of greenhouse gas emission

The primary anthropogenic (human-induced) greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFC_S), ozone (O_3), carbon monoxide (CO), non-methane volatile organic compound (NMVOC) and nitrogen oxides (NO_X) (WB, 1998). Literature review indicated that the total emission of greenhouse gases in the Sudan for 1995 amounted to 25,800 Gg. CO_2 is the main greenhouse gas which constituted more than 75% (20,100 Gg) of the total greenhouse gas emission, followed by CO (3,300 Gg), CH_4 (2,000 Gg), and small amounts of other gases such as NMVOC, NOx, N_2O. Biomass energy was estimated to emit about 21,900 Gg of CO_2, constituting more than 80% of the total CO_2 emitted in the energy sector. Agriculture was dominant in CH_4 emissions, estimated at 1,700 Gg, which is more than 86% of the total CH_4 emissions in the Sudan (MEPD & HCENR, 2003).

FAO (1999) has estimated the rate of greenhouse gas emissions from fuelwood burning both for Africa and the Sudan for 1996. According to this estimation, for the whole continent of Africa, the total amounts of 597,553,000 t CO_2, 1,635,000 t CH_4, 27,252,000 t CO, 2180 t N_2O, 545,000 t NO_X and 3,270,000 t NMVOC were emitted. Sudan’s contribution to these emissions was 8,814,000 t CO_2, 24,100 t CH_4, 402,000 t CO, 300 t N_2O, 8,000 t NO_X, and 48,200 t NMVOC.

The present study suggests that the annual quantity of fuelwood required for the 3,450 brick making industries in the Sudan would be 328,600 t dry matter. Due to the burning of that quantity fuelwood, 542,200 t CO_2, 2,366 t CH_4, 20,700 t CO, 16 t N_2O, 588 t NO_X and 383 t NO would be emitted per annum. By considering both two categories of biomass fuels (fuelwood and dung cake) together which are currently used in the brick making industries in the Sudan, the total emissions from the 3,450 brick making industries in the Sudan would be 662,600 t CO_2, 2,900 t CH_4, 25,300 t CO, 20 t N_2O, 720 t NO_X and 470 t NO per annum, while the total amount of carbon thus released would be 180,700 t (Tab. 18).

5.3 Prospects of the use of bagasse processed fuel blocks in the brick making industries of Sudan

Bagasse from the sugar industry is one of the most important agricultural residues available in Sudan, suitable for processing into compact solid fuels which can be a good substitute for fuelwood in the brick making industries of Sudan. BENS (1996) found out in their study, (1) the use of bagasse processed fuel blocks in the brick making sector is technically and economically feasible and bagasse blocks can replace 80% of wood use in the brick making industries of Sudan (2) the utilization of this resource (bagasse) will have a significant impact on the environment by conserving fuelwood consumed in the brick making industries and consequently will relieve pressure in degrading forest resources and (3) the use of bagasse as fuel instead of fuelwood will contribute to the reduction of greenhouse gas emissions as trees left to grow in the forest can be act as carbon sink and will reduce the harmful effect of methane gas produced from bagasse by leaving them in the vicinity of sugar factories for a long period.

There are five sugar factories in the Sudan. The first one named Guneid Sugar Factory constructed in Butana State of Central Sudan in 1968 followed by New Halfa Sugar Factory at Kassala, Eastern Sudan in 1968. The other three were established in 70^{th}; Sennar in 1974, Assalya in 1976 and Kenana in 1979. From these factories approximately 200,000 tons of bagasse is produced as by-product every year. Only Kenana Sugar Factory is utilizing its all bagasse for satisfying its own requirement for energy, although not all its requirement is supplied from bagasse. So, bagasse from other four sugar factories can be used for bagasse fuel blocks production. BENS (1996) predicted that the demand of bagasse fuel blocks by brick kilns might be less than the bagasse fuel blocks production if all available bagasse can be utilized. For this, in 1985 trials of bagasse fuel blocks production started at New Halfa Sugar factory with the technical support of FAO/FNC. Later on two manual units were installed at the New Halfa area for producing bagasse fuel blocks. In 1989, a third unit of 10 presses was established at the same place with the financial assistance of EEC. Later, in 1993 another unit was established at Guneid Sugar factory with the technical and financial assistance of FAO/FNC. Under the financial aid of same project other two units were established at Senner in 1994 and at Assalaya in 1994. Until 1995, there are 7 units located in four sugar factories with total number of 36 presses. But unfortunately, almost all these units are no longer working due to the continuous increase of price of molasses[26], which is used as binder for the production of bagasse fuel blocks within the range of 33-40%. BENS (1996) also recommended that the amount of molasses produced now in the sugar factories will not be sufficient if the whole available quantity of bagasse is used for bagasse fuel blocks production. Accordingly, the total possible amount of bagasse fuel blocks will be less than the estimated total demand of brick kilns for fuel. This demand can be satisfied if clay or filter cake[27] is used as a binder in producing bagasse fuel blocks.

However, use of densified agricultural wastes of bagasse including ground nut hells and cotton stalks for firing of clay bricks is highly recommended as an alternative fuel. Available, cheap compressed agricultural wastes will encourage traditional brick makers to use them separately or in combination with wood. To achieve this, further research should carry out to establish densifying (briquetting[28]) plants and to encourage brick makers to shift from fuelwood to densified fuel blocks.

5.4 Meeting of fuelwood demand for brick making industries in the Sudan by sustainable fuelwood plantations

Present study revealed that small scale sustainable fuelwood plantations was already established by Kenana Sugar Factory at White Nile State (irrigated Sunt plantation-1,450 feddans), by FNC at Kassala State (irrigated Eucalyptus plantation 172 feddans) and at Gezira State (Sunt reserve-375 feddans). From the literature study it is also known that total annual brick production in the Sudan is about 2.8 billion. Having obtained annual brick production in the Sudan, it is easy to estimate the area of forests to be reserved annually for sustainable fuelwood production for the brick making industries of Sudan. Here, Sunt (*Acacia nilotica*) is considered to be the sole fuelwood species for calculation and assumed that sustainable plantation is not harmful for potential deforestation and greenhouse gas emission as it maintains the stock sustainable in the forest and acts as

[26] Molasses is the final effluent obtained in the preparation of the sugar by repeated crystallization (BENS, 1996).

[27] Filter cake is a waste material resulting from washing sugar cane in sugar industry, composed mainly of clays and some parts of the roots of the canes (BENS, 1996).

[28] Briquetting: Material (sawdust, crop residues, and charcoal fines) compacted under pressure (densification) to improve characteristics of materials for transport and use as energy source. Because they are compressed and have low water content, they have a higher energy density than ordinary wood and need less storage space. Also called "white coal" (WMO, 2001).

carbon sink simultaneously. According to Hamid (1996), the following assumptions are made:

1,000 bricks need 45 kg of wood (one Kontar)
One m^3 of stacked Sunt (*A. nilotica*) wood = 440 kg
One feddan produces = 37 m^3 stacked Sunt

2,800,000 thousands (2.8 billion) bricks require = $\dfrac{2,800,000 \times 45}{440 \times 37}$
= 7739.55 ≈ 7740 feddans = 3250.8 hectares (as 1 feddan = 0.42 hectares)

Hence, 3,250 hectares of *A. nilotica* plantation is the annually required forest area to cover the fuelwood demand of brick making industries in the Sudan. But for sustainable management, a total of 65,000 hectares of *A. nilotica* plantation is needed with 20 age gradation plots, considering that *A. nilotica* plantation is managed on a basis of 20-year rotation for fuelwood production in the Sudan (Fagg, 1992). If this amount of *A. nilotica* fuelwood plantation is not provided in a sustainable base, brick production could be considered as a main contributing factor to the problem of deforestation.

5.4.1 Energy plantations

Use of biomass fuels as a renewable, sustainable and clean energy source instead of fossil fuels have received the interest in the recent years concerning serious environmental issues like global climate change. Energy plantations are one of the attractive options for addressing CO_2 concerns, because both growth and conversion involve recycling atmospheric carbon, resulting in no net addition of CO_2 into the atmosphere. The amount of carbon sequestered may be greater than that released by combustion because most energy crops are perennials and they are harvested by cutting rather than uprooting. Hence, the roots sequester carbon and regenerate the following year (WMO, 2001).

Nowadays, especially in developed countries, there is a growing cooperation on energy policy and technology issues, often referred to as the “3Es”: economic development, energy security, and environmental protection. Plantation of energy crops would be the solution to reconcile these “3Es”. Energy crops can be grown on farms in potentially large quantities. The best energy crops are (WMO, 2001):

Trees: Those grow very fast and will resprout after being cut off close to the ground, a process called "coppicing". The best varieties for temperate climates are sycamore and sweet gum; for tropical climates, eucalyptus; and for cooler and humid climates are poplar, maple, and willow.

Grasses: Thin-stemmed perennial grasses, like switch grass and big bluestem, grow quickly in different climates and can be harvested for up to 10 years before replanting. Thick-stemmed perennials like sugarcane and elephant grass can be grown in hot and humid climates.

These crops are chosen because of their characteristics of growth, manageability, and environmental impacts. Some of these crops are being developed through genetic engineering for maximizing growth ("super trees") or for consuming much more CO_2 ("smog-eating trees") than normal trees. For example, straw and willow have the lowest CO_2 emissions per unit of energy delivered and Switch grass has a high potential for sequestrating carbon (Börjesson, 1998; FAO/FEF, 1998; WMO, 2001). Bearing in mind, the study recommends for energy plantation in the Sudan and suitable species would be eucalyptus, can be consumed as fuelwood in the brick making industries and sugarcane for producing bagasse fuel blocks.

5.5 Impacts of global climate change in the Sudan

5.5.1 General aspects

Impacts of global climate change due to enhanced greenhouse gas emission in the Sudan can be discussed on the estimated increase or decrease in temperature and precipitation for the projection years 2030 and 2060 as well as sorghum and millet yield scenarios for the same projection years.

To foresee climate change scenarios, the data collected from five stations (El Obeid, En Nahud, Rashad, Kadugli and Babanusa) of Kordofan region which is located in mid-western Sudan between latitudes $9^0 30^/$ and $16^0 24^/$ North and longitudes 27^0 to 32^0 East. Kordofan region ranges across desert and semi-desert in the North, to moist, sub-humid and rich savannah in the South. Arid and semi-arid zones make up the largest segment of Kordofan's land area and the data collected at these stations tells a story of a varied regional climate. For discussion, the data adapted from MEPD/HCENR (2003) and finally analyzed under the following heads:

5.5.2 Impacts of global climate change on temperature

Due to global climate change, Sudan's temperature will increase for both the projection years 2030 and 2060. For future projections, the year 1990 was considered as the base year. For the projection year 2030, it was estimated that temperature will increase 0.4-1.0 ^{0}C in all five stations (El Obeid, En Nahud, Rashad, Kadugli and Babanusa) of Kordofan region and gradual rise will continue for the projection year 2060 ranging between 1.0-1.8 ^{0}C. It was also observed that station El Obeid will be worse affected than the other stations by gradual rise of temperature during the projection years (Tab. 22).

Table 22. Estimated increase in temperature for the projection years 2030 and 2060

Projection Years/Station	Temperature (^{0}C)			Increase (^{0}C)	
	1990	2030	2060	2030	2060
El Obeid	27.3	28.3	29.1	1.0	1.8
En Nahud	27.5	28.4	29.2	0.9	1.7
Rashad	26.8	27.2	27.8	0.4	1.0
Kadugli	28.1	28.8	29.4	0.7	1.3
Babanusa	28.5	29.2	29.8	0.7	1.3

(Adapted and modified from MEPD/HCENR, 2003)

5.5.3 Impacts of global climate change on precipitation

Precipitation will also be affected by global climate change either by increasing or decreasing for the projection years 2030 and 2060. Precipitation will increase at the stations El Obeid and En Nahud ranging between 10-12 mm by 2030 and 19-21 mm by 2060 while it will decrease at the stations Rashad, Kadugli and Babanusa ranging between 2-8 mm by 2030 and 3-15 mm by 2060 (Tab. 23).

Table 23. Estimated increase or decrease in precipitation for the projection years 2030 and 2060

Projection Years/Station	Precipitation (mm)			Increase or decrease (mm)	
	1990	2030	2060	2030	2060
El Obeid	318.0	328.9	337.4	10.9	19.4
En Nahud	335.9	347.6	356.7	11.7	20.8
Rashad	717.7	715.8	714.3	-1.9	-3.4
Kadugli	633.1	630.5	628.2	-2.6	-4.9
Babanusa	497.3	489.0	482.3	-8.3	-15.0

(Adapted and modified from MEPD/HCENR, 2003)

5.5.4 Impacts of global climate change on Sorghum and millet yield

Production of agricultural crops, sorghum and millet, will decrease substantially due the result of global greenhouse effect. Production of sorghum will decrease in all the stations except station Rashad by 215-346 kg/ha by 2030 and 253-357 by 2060. It was also observed that surprisingly the production will remain constant at Rashad station for both the projection years (Tab. 24). Millet production will also decrease in all the five stations during the two projection years ranging between 56-216 kg/ha by 2030 and 69-255 kg/ha by 2060. The study also observed that millet production at Kadugli will decrease notably than the other stations while production loss will be a lesser amount at El Obeid station for the both projection years (Tab. 25).

Table 24. Sorghum yield scenario for the projection years 2030 and 2060

Projection Years/Station	Yield (kg/ha)			Decrease (kg/ha)	
	1990	2030	2060	2030	2060
El Obeid	495	150	143	-345	-352
En Nahud	631	285	274	-346	-357
Rashad	>748	>748	>748	No change	No change
Kadugli	>748	533	495	-215	-253
Babanusa	>748	417	379	-331	-369

(Adapted and modified from MEPD/HCENR, 2003)

Table 25. Millet yield scenario for the projection years 2030 and 2060

Projection Years/Station	Yield (kg/ha)			Decrease (kg/ha)	
	1990	2030	2060	2030	2060
El Obeid	112	56	<43	-56	-69
En Nahud	204	86	81	-118	-123
Rashad	433	367	331	-66	-102
Kadugli	433	217	178	-216	-255
Babanusa	343	159	139	-184	-204

(Adapted and modified from MEPD/HCENR, 2003)

5.6 Limitation and uncertainty of the study

A central limitation in this study is the use of some ECE/FAO and IPCC default values for the estimation of potential deforestation and greenhouse gas emission by the brick making industries of Sudan due to the lack of local factors. Despite the fact that, in some cases, these default values do not accurately reflect Sudan’s specific, unique conditions.

Apart from that, a major area of uncertainty exists in the estimation of the quantity of fuelwood and dung cake consumption by the brick making industries of Sudan, which is significantly important to estimate potential deforestation and the rate greenhouse gas emission in the atmosphere. Data of biofuels consumption quantity were collected from the interviews of entrepreneurs rather than direct field measurement.

6 CONCLUSIONS AND RECOMMENDATIONS

The present study focused on the annual emission of greenhouse gases and the potential maximum rate of deforestation in the Sudan caused by the brick making industries that use fuelwood or dung cake as fuel. In general, Sudan contributes a small amount of greenhouse gases to the atmosphere compared to the rest of the world. In comparison, in 1995, the total global amount of carbon emitted from energy activities was estimated at 6 billion t. Sudan's contribution to this was very modest, even in comparison to many other developing countries. This is also seen in the 1995 per capita emission of CO_2 in the Sudan, which was only 3 t per person (i.e., 89,220 Gg/28.7 million people; MEPD /HCENR, 2003).

The present study suggested a considerable amount of fuelwood consumed by the brick making industries in the Sudan and this sector potentially acting as an agent of deforestation. Changes in the environment due to degradation of forest resources and emissions of greenhouse gases are key issues today in the national, regional and global contexts. In the following, recommendations are listed that could mitigate deforestation and forest degradation and reduce greenhouse gas emissions originating from the brick making industries in the Sudan:

I. Use of densified agricultural waste, such as bagasse fuel blocks, groundnut hulls and cotton stalks, for firing of clay bricks is highly recommended. To achieve this, densifying (briquetting) plants should be established (cf. Hamid, 1994);

II. The use of bagasse fuel blocks instead of wood in the brick making industries in Sudan would relieve pressure on forest resources. This would also contribute to the reduction of greenhouse gas emission in two ways, (i) by reducing the pressure on forests and allowing trees and forests to act as stronger carbon sinks, and (ii) by utilizing bagasse, also reducing the harmful effect of methane gas generated from this waste when it is left for a long period in the vicinity of sugar factories (cf. BENS, 1996);

III. The open-top Hoffman kiln can be introduced for efficient use of alternative fuels, such as fuel oil and densified agricultural waste (cf. Hamid, 1994);

IV. Introduction of traditional agro-forestry system in consistent with natural forest management;

V. Production of fuelwood with higher calorific value by selecting suitable tree species and recommending them for plantation establishment and sustainable natural forest management;

VI. Establishment of energy plantation with suitable species such as eucalyptus for fuelwood supply in the brick making industries and sugarcane for producing bagasse fuel blocks;

VII. Intensive afforestation[29] and reforestation[30] programmes should be undertaken by Forests National Corporation (FNC) with the help of NGO's and ensuring the participation of local people; this would also contribute to more sustainable fuelwood use and less harmful greenhouse gas emission

Further Research

Due to the growing concern of global climate change, its impacts on environment and the use of biomass fuels as a renewable, sustainable and clean energy source; a comprehensive research could be carried out on, "Greenhouse gas emissions from biofuel combustion in the Sudan". In this connection, a high priority should be given for the inclusion of other significant industrial fuelwood consumption sectors such as bakeries, lime curing and vegetable oil industries in the future research project in addition with brick making industries.

[29] Establishment of a tree crop area where it has always or long been absent. (FAO as cited in WMO, 2001).

[30] Planting of forest on lands that have, historically, previously contained forests but which have been converted to some other use (IPCC as cited in WMO, 2001).

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APPENDICES

Appendix 1

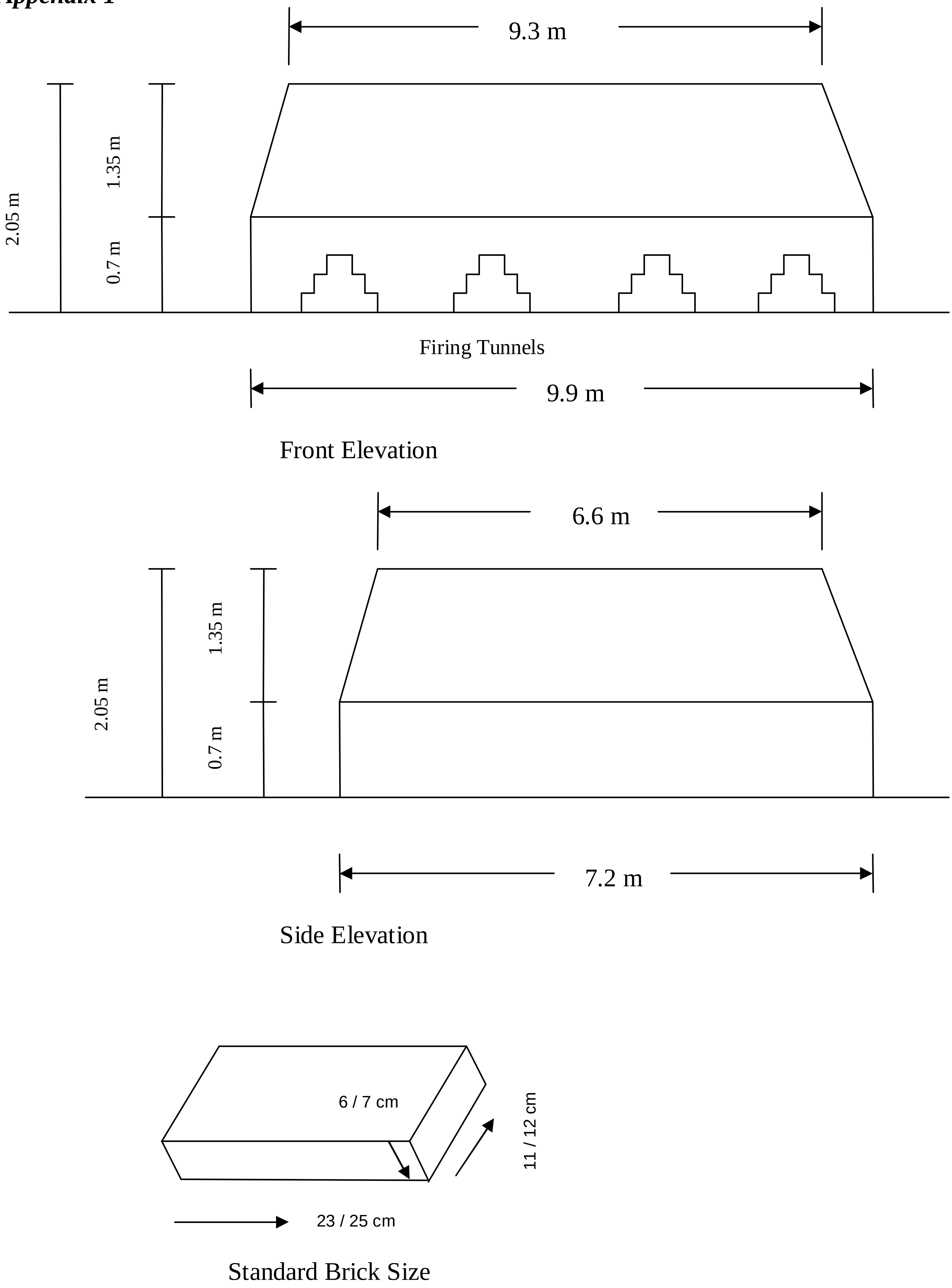

Figure 2. Sudanese traditional fired clay brick kiln: Intermittent (Scove) Kiln and standard brick size (Adapted and modified from BRRI & CRATerre, 1984).

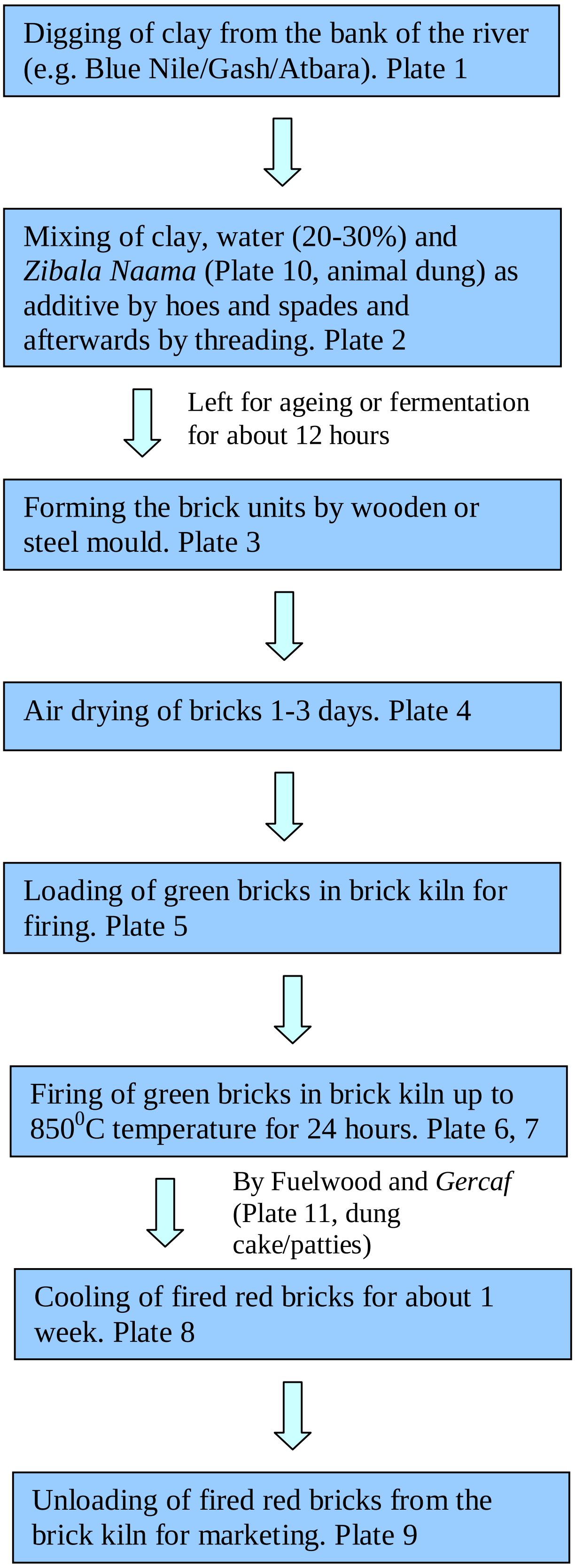

Figure 3. Flow chart of traditional fired clay bricks production process in Sudan. Plates are given on Appendix 2.

Appendix 2

Plate 1: Digging of clay from the bank of the river (e.g. Blue Nile/Gash/Atbara)

Plate 2: Mixing of clay, water (20-30%) and *Zibala Naama* (animal dung) as additive by hoes and spades and afterwards by threading

Plate 3: Forming the brick units by wooden or steel mould

Plate 4: Air drying of green bricks 1-3 days

Plate 5: Loading of green bricks in brick kiln for firing

Plate 6: Arrangement of firing of green bricks by fuelwood and *Gercaf* in brick kiln up to 850^{0}C temperature for 24 hours

Plate 1-6: Traditional fired clay bricks production process

Plate 7: Firing of green bricks (by fuelwood and *Gercaf*) in brick kiln up to 850^0C temperature for 24 hours

Plate 8: Cooling of fired red bricks for about 1 week

Plate 9: Unloading of fired red bricks from the brick kiln for marketing

Plate 10: *Zibala Naama* (animal dung in dust form) used in clay mix

Plate 11: *Gercaf* (animal dung cake) used for brick burning

Plate 12: Mr Ali Ahmed Ibrahim, Secretary of Brick Making Owners' Association, Khartoum, interviewed by the Author

Plate 7-11: Traditional fired clay bricks production process